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Volume X APRIL, 1945 Number 2

GEOPHYSICS

A Journal of General and Applied Geophysics

Published by

The Society of Exploration Geophysicists

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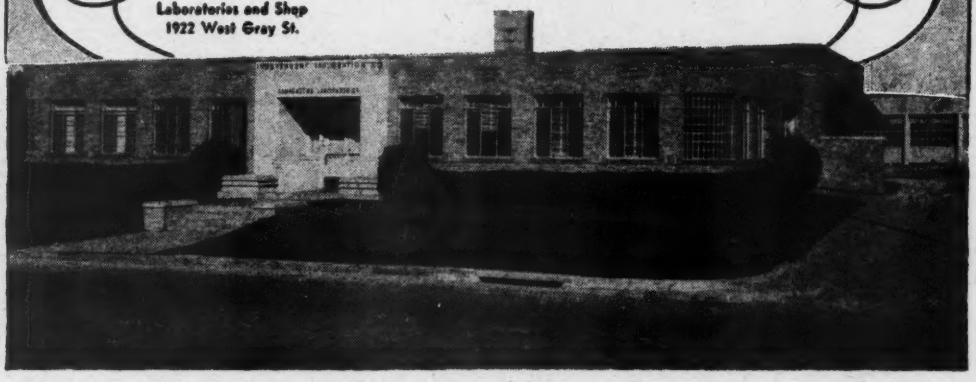

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Entered as second-class matter September 7, 1938 at the post office at Menasha, Wisconsin, under the Act of March 3, 1879. Acceptance for mailing at the special rate of postage provided for in the Act of February 28, 1925, embodied in paragraph 4, section 538, P.L.&R., authorized March 19, 1941.

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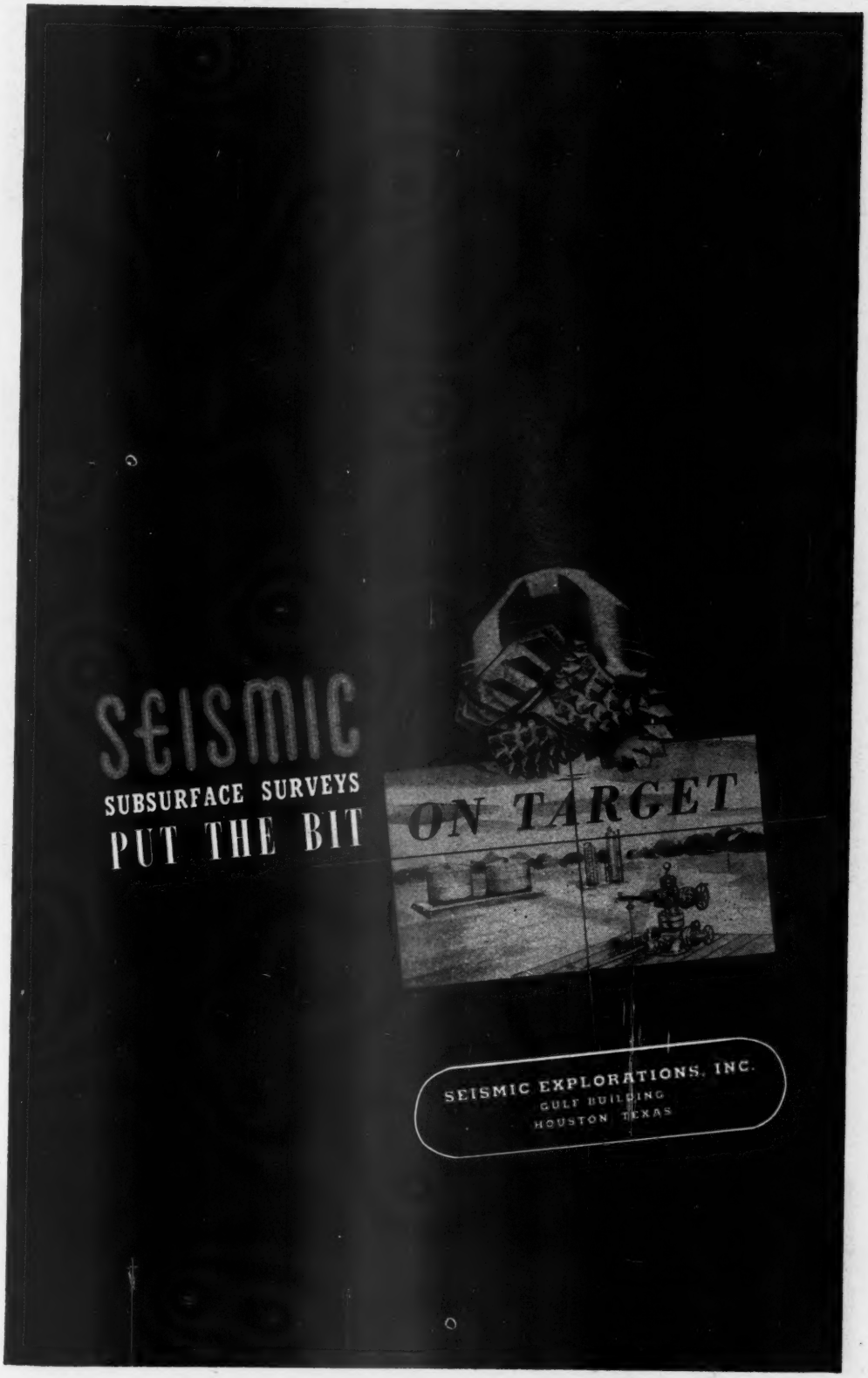
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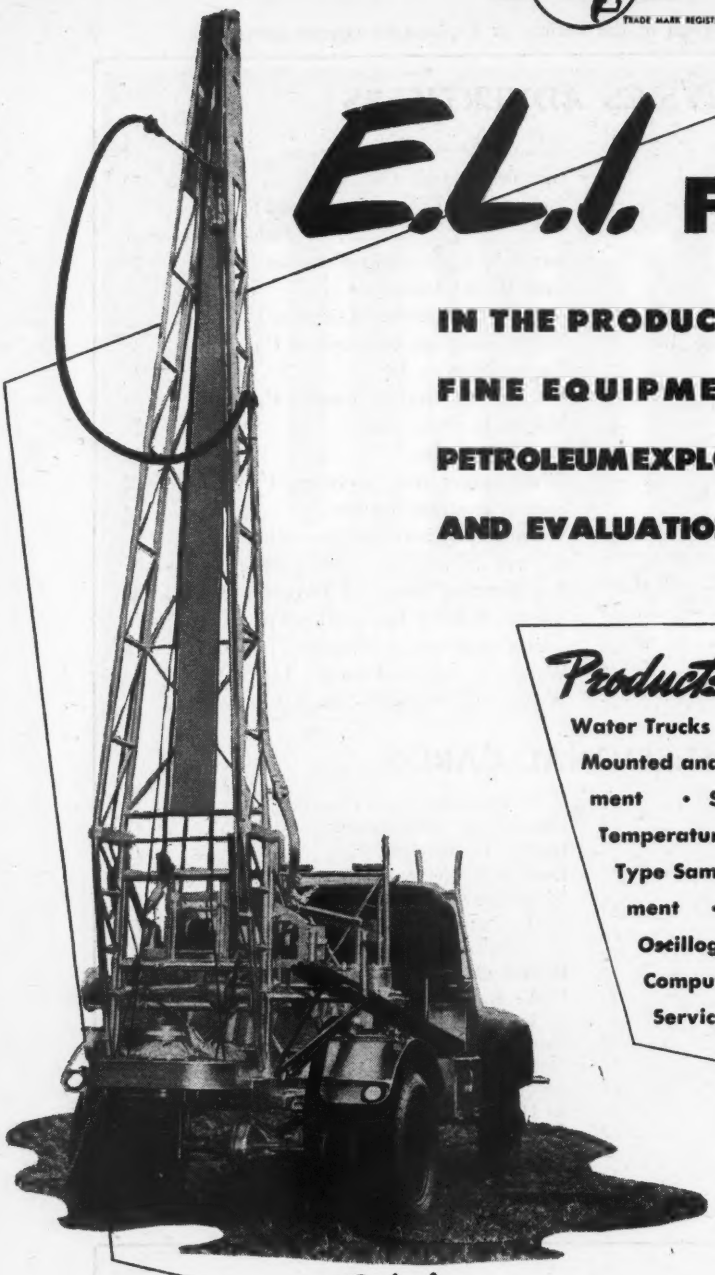

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GEOPHYSICS

A Journal of General and Applied Geophysics

ORGANIZATION OF GEOPHYSICAL PARTIES FOR FOREIGN EXPLORATION*

C. H. DRESBACH†

ABSTRACT

Current and future requirements of petroleum have produced a strong demand for American personnel, equipment and techniques to be employed in the world-wide search for oil. Different, and sometimes much more difficult conditions are frequently encountered from those customarily met in the exploration for oil in the United States. A brief consideration of some of these factors is the purpose of this paper. It is concluded that while careful preliminary planning and the design of equipment in the light of accurate information on conditions to be encountered are highly vital factors, the demonstrated and trustworthy character of the personnel conducting the operations is the biggest guarantee of success in the undertaking.

INTRODUCTION

It is rapidly becoming evident that an increasingly large percentage of the U. S. oil industry's future exploration programs will be located outside the boundaries of this country. This will apparently be true not only for the major companies but to at least some extent for some of the smaller integrated companies and larger independent producers, as well as, of course, the various contracting, consulting and service companies. Special conditions encountered in much foreign work make it necessary to consider many factors which are not encountered in domestic programs of geophysical exploration for oil. Although extremely difficult working conditions are frequently met in domestic operations by company and contract crews, the large store of past experience, the availability of fresh supplies, replacement or new equipment, and the proximity of the helpful home office make their surmountal more or less a matter of routine. Contrariwise, foreign operations are frequently conducted under much more difficult conditions, supplies and equipment can be secured only after long and

* Manuscript received March 4, 1944. An earlier version was presented in fulfillment of the thesis requirements of the professional E.M. degree at the Missouri School of Mines, 1938.

† Western Gulf Oil Company, Los Angeles, California.

costly delays, and the distance and inaccessibility of the home office leave practically all decisions to the party executive. While the following résumé of some of the conditions and problems to be encountered may appear rather elementary and perhaps even trite to the old time foreign operator, experience has shown that careful consideration of some significant features is sometimes overlooked by even the old hands while the pitfalls awaiting the uninitiated are so numerous as to justify extended studies. Unless the majority of present day authorities are in error the ranks of companies and operators making their first foreign exploration venture are to grow rapidly and strongly. To them in particular these comments are directed.

For permission to present this paper special appreciation is expressed to Dr. K. C. Heald, Staff Geologist of the Gulf Oil Corporation, and to Dr. E. A. Eckhardt, Vice President and Director of the Geophysical Department of the Gulf Research and Development Company. All material presented is derived from the writer's personal experiences and/or contacts with other men who have been located in areas foreign to him. Opinions expressed herein are strictly those of the writer alone.

LOCATION

Naturally the locations of areas or countries where foreign work is projected by various companies are ordinarily not made public. However, it appears to be the general opinion that the most active provinces will be generally as follows in very approximate order: (1) South America, and particularly the northern portion which includes Venezuela and Colombia; (2) the Near and Middle East, particularly the Persian Gulf region; (3) East Indies; (4) Canada.

Efforts to expand the list naturally could not produce a complete roster, but the following are known as countries in which geophysical investigations have been made within recent years, are now being conducted, or are contemplated within the near future (at least in near post-war years). The last classification is based either on geological investigation ordinarily a prerequisite to geophysical activities or in a few cases includes those in which geological conditions are such that oil exploration will likely be conducted there. Some of the countries cited are those in which only contract companies may be able to operate because of nationalization of the industry. Listed alphabetically and without regard to rank are: Angola, Arabia, Australia, Austria, Bolivia, Borneo, Brazil, Burma, Canada, Chile, China,

Colombia, Congo, Costa Rica, Cuba, Denmark, Dominican Republic, Ecuador, Egypt, England, France, Germany, Guatemala, Haiti, Honduras, Hungary, India, Iraq, Iran, Java, Kuwait, Madagascar, Mexico, Morocco, New Guinea, New Zealand, Nicaragua, Palestine, Panama, Paraguay, Peru, Philippines, Poland, Portugal, Qatar, Roumania, Sumatra, Syria, El Salvador, Trinidad, Turkey, Uruguay, U.S.S.R., Venezuela. Subsequent developments may well add the names of other countries or territories where plans and prospects are now unknown or overlooked.

It is obvious that in the countries listed above the widest possible range of physical conditions will be encountered. These may vary from sparsely settled localities in New Guinea where native labor is almost unavailable, to the densely populated areas of England, where the very density of the population hinders operations. Practically never is a geophysical program undertaken until at least reconnaissance, and usually fairly detailed, geological studies have been made. Obviously, there are large areas, such as the plains, llanos, selvas or pampas, where surface geology is handicapped by the absence of surface exposures and of outcrops in adjacent uplifted areas. When subsurface data are also lacking, geophysicists must start from scratch. However, practically without exception the executives of the producing company or group of promoters have more or less general information upon conditions in the area of prospective geophysical operations. Few regions are entirely uninhabited and information gathered in trade relations is available to supplement that furnished by advance geologists.

OPERATIONAL PREREQUISITES

Since the locations in which exploration activities are to be conducted are located within the limits of friendly sovereign nations or their territories it naturally follows that certain requirements imposed by them will have to be met as conditions for operations. Concessions, leases and political considerations are outside the scope of this paper. However, it is pertinent to state that various governmental policies inevitably affect the planning and conduct of the exploration program. Basically, the type of operations will normally be one of these three: (1) The development proceeds under the terms of a concession granted to a company upon the basis of agreements with that government as to conditions, terms, royalties, etc.; (2) The government concerned and/or national capital or interests, participate to varying degrees in the

actual operations; and (3) The government concerned has nationalized petroleum resources, and operations by other than nationals of that country are restricted to contracting companies or individuals working directly for that government or, more likely, its national operating company.

As stated, the political requirements that must be met are outside the field of this paper but they are very important factors in the planning and conduct of operations. While they are primarily the concern of the operating executives close cooperation and exchange of information between them and those planning the actual geological and geophysical programs is absolutely essential. A thorough knowledge and understanding in advance of special or unusual operating conditions or requirements may save long and costly delays or even mean the difference between success and failure.

A favorite examination question of the late Dr. C. L. Dake, Professor of Geology at the Missouri School of Mines, was, "What should be the first step in starting work in a new area?" The expected answer was, "Find out everything possible about the area before ever starting actual work there." So strongly did he feel that this obvious answer should be given that the luckless students who failed to give it almost certainly were classified as lacking in horse sense and thus not equipped with the first prerequisite of a successful career in exploration. Not only were geological data included in this study, but any and all facts that might possibly be of value in the proposed work. Nowhere is this advice so pertinent as in a difficult foreign area where even a little information may save months of effort and needless duplication.

CLIMATE AND LIVING CONDITIONS

With the exception of Canada and the European countries, most of the areas of primary interest are either tropical or semi-tropical. The humidity and rainfall vary widely but in many areas at least part of the year they are apt to be very high. In the majority of cases, and particularly in the Latin-Americas and the Near, Middle and Far East where most of the activity is concentrated, normal living accommodations for the field personnel are not available. Hence the problem of housing and feeding a considerable number of men under tropical field conditions becomes of major importance. In most instances the actual details of the camp operations are handled by the exploration department of the producing or contracting company for whom the work is being done. If not, these matters will require the full

attention of at least one man under the supervision of the Party Chief or Supervisor. These problems are discussed more thoroughly under the heading, "Equipment and Supply Organization."

Climatic changes in the plains areas of Latin-America tropics are primarily those due to, or closely associated with, variations in the amount of rainfall. In those countries in the vicinity of the Caribbean Sea the typical principal rainy season begins around May and ends about November. During this period torrential rains fall frequently. Climatic conditions vary widely in any country. In East Central Mexico, for example, the damp cold at nights in January and February calls for three or four blankets, while during April and May the writer has experienced daily temperatures of 120°F. in the office tent, which was covered by a tent fly and shaded by trees. The humidity was almost 100%. Climate in these tropics is largely influenced by the altitude—with its consequent effect upon the moisture-carrying wind currents. In some unusually favorable areas, such as the present exceedingly important Eastern Venezuela llanos, in and adjacent to the State of Anzoategui, geophysical operations may usually be carried on with only slight hindrance from the seasonal rains. This is due to the well drained, sandy soil and the relatively moderate amount of rainfall. However, conditions vary from year to year, and in such years as 1938 when the rains were unusually heavy, operations may be retarded to a mere fraction of their former speed.

Lying west of the Venezuelan short grass llanos are the tall grass llanos of the States of Apure and Barinas, (formerly Zamora). A heavy soil and torrential rains produced by the proximity of the Andes Mountains to the west produce entirely different operating conditions. Combined with these climatic changes is a scarcity of roads or trails passable by trucks that require a considerably altered technique. In the dry season trucks and cars carrying geophysical equipment can make their way cross-country, although the mortality in springs will be heavy. However, when the heavy rains begin in this area an automotive transported geophysical crew must hustle its equipment from the back country to escape being mired down for months. In many areas passable by trucks in the dry season mules become the only mode of transport when the rains begin. Later, they too may bog down and bulls or oxen will transport the small amount of native freight moving. Down towards the Colombian border immense areas stand one to several feet under water and only native canoes or bongos move over the inundated tall grass llanos country. In such extensive areas

operations during the rainy season can be conducted only with marine or amphibious equipment. Even then, strong and rapid fluctuations in water levels introduce complications.

Illustrative of the amazing lack of preparation into which even an experienced organization sometimes slips is the experience a number of years ago of a major company which suddenly decided to embark upon a new program of geological exploration just east of the Venezuelan Andes. With no thought of the vagaries of a tropical climate a number of geologists and engineers were shipped down to start work. They arrived in June and found one of the worst rainy seasons in years. Consequently, for the next few months several high-priced men spent the time bogged down in little native towns waiting for workable conditions. Preliminary investigation or even consultation with any of the many available individuals engaged in trade or cattle buying in this area could have easily given the information on climatic conditions that would have saved this waste. Reference to an encyclopedia or a good publication on physical geography and climate would even have given valuable information. While such lapses are rare the lack of information by the home offices on climatic conditions in areas to which geophysical crews are to be sent is frequently amazing. Careful attention to this feature will pay large dividends.

Even in desert or semi-desert areas near the tropics such as Kuwait and Iran in southwestern Asia seasonal variations in the climate are a controlling factor in an exploratory campaign. For three to six months of the year, or roughly from April to September, a hot wind blows in some localities. Even the wandering Bedouin and his herds migrate from some of the desert areas until more bearable weather is resumed. For unacclimated foreigners to attempt to work during such times would often be foolhardy. Much can be learned from observation of the natives' customs and habits, for while his standards of living, health, and sanitation may be utterly primitive, the processes of evolution have taught him how to adapt himself to that particular environment.

Consideration of tropical climate leads naturally to that of insects. While at first thought it would seem that they could little affect a geophysical program their effect on living conditions and the morale of the personnel is often most important. There are many individuals who seem constitutionally unable to stand the constant annoyance and irritation of the swarms of insect pests usually encountered in the tropics, and whose morale soon disintegrates under such conditions. Even the most phlegmatic dispositions acquire an extra edge under the

constant attack. The Eastern Llanos of Venezuela, fairly well drained and usually swept by a breeze, are freer of insect pests than most tropics. The humid climate of portions of Mexico, western and west-central Venezuela, Colombia, Brazil, the South Pacific areas, etc., produce an insect condition impossible of comprehension to those who have not worked there.

As a final example of possible working conditions, the production departments of companies operating in Iran, Arabia, Iraq, and Bahrein must have air-conditioned, specially constructed tropical houses and various recreational facilities for their employees. However, the geophysical and geological crews who preceded them and who spent months and years finding the oil lived in tents, often had no refrigeration, and for recreation were chiefly confined to the usual evening poker game.

HEALTH

Sickness or injury of a member of a geophysical crew in the States ordinarily means only the inconvenience of securing a replacement or perhaps doubling up of duties for a short time. Operations abroad are usually conducted with a too bare minimum of American personnel and replacements are some thousands of miles, and more important, perhaps weeks or months away. While the airplane has cut down travel time greatly, the formalities required in many instances before work permits, passports and other immigration requirements are satisfied may necessitate weeks or even months in some instances before a new man can join the crew. Lacking trained replacements on the ground, even the temporary loss of a man becomes a much more serious matter.

As an elementary principle it is obvious that any individual selected for foreign service should be in good physical condition. A thorough physical examination is essential. Typhoid shots and smallpox vaccinations are standard precautions. Other special inoculations may be required. Troubles with the teeth and the stomach (particularly stomach ulcers) are encountered more frequently under tropical conditions in a field camp. This is presumably due to the changed living conditions, bad water, lack of milk and fresh vegetables, and sometimes the monotonous and perhaps rather greasy diet often prepared by the cooks. Individuals with a "touchy" appendix are merely inviting serious trouble, for in a remote area where communication with hospital facilities may be a matter of several days or even weeks,

an appendicitis attack may easily be fatal, whereas under ordinary domestic circumstances it would mean merely a routine operation. Those required to wear eye-glasses should carry at least one extra pair, and also a copy of the prescription, which can usually be filled in some large city of the country. Present day air travel facilities, however, have very greatly reduced emergency health hazards.

The twin scourges of many tropics are malarial fever and dysentery. The first is mostly encountered in the more humid tropics while the latter seems to be prevalent in all tropical areas, and particularly where cleanliness and sanitation are especially bad. As well known, malaria is transmitted by the female Anopheles mosquito, and the only sure preventative is to avoid being bitten by an active carrier. As the mosquito is most active at night an invariable rule should be to sleep under nets, or if in a permanent residence, in a very well screened room which is nightly sprayed with an insecticide as a matter of habit. The usual cure for malaria is quinine, taken either by mouth or in shots, and/or the newer drugs, plasmaquin(e) and atabrin(e). Some of the new insecticides developed during the war, such as DDT, should be of great value both for safety and comfort. The writer, having gone from over 165 pounds to less than 125 pounds weight in a few months during a malarial siege can testify to its effects.

Dysentery is of two types, amoebic and fungus. It may be contracted in a variety of ways, but usually either from contact, even though very remote, with a carrier of the disease, or else from eating contaminated food. In many areas all fresh fruit and vegetables are potential sources of infection and require boiling or treatment with a disinfectant such as a dilute potassium permanganate solution. Treatment of the amoebic type usually requires injections of emetine, while the fungus type may be treated with a variety of medicines, usually bismuth compounds.

A variety of infections from insect bites and the like are frequent. Gusanos (worms) hatched from an egg laid in the human flesh by a large mosquito-like fly must sometimes be extracted by a doctor when located in the more vital portions of the body. Infected tick and leech bites are common. The first rule of health in the tropics is sanitation and cleanliness. Obviously, at least one member in authority on a party, and preferably its chief, should have had previous experiences under similar conditions. Beyond the above mentioned few items there are literally dozens of precautions that should be taken that only experience can teach. Practical information the experienced leader may

impart is apt to range all the way from the invariable habit of shaking out one's boots in the morning to dislodge scorpions, centipedes or snakes that may have taken refuge there during the night, to the judicious observation that most foreign contracts carry the provision that anyone contracting a venereal disease returns home at once at his own expense. Of course, Canada, England, Denmark and some of the Continental countries have living conditions similar or equal to our own, and in such cases only the ordinary care in preserving health is required.

A very excellent and comprehensive article entitled "Protecting the Health of Oil Industry Employees" appeared in the September 1944 issue of "World Petroleum." It is by Drs. W. J. Denno and K. R. Fourcher, General Medical Director and Assistant Medical Director, respectively, of the Standard Oil Co. (N. J.). While it is perhaps primarily concerned with the bulk of the foreign personnel who are housed in permanent or semi-permanent camps it carries sufficient information on transient exploration crews as well as general background data to be a very valuable reference guide to anyone concerned with the health of oil company personnel (and particularly foreign), away from normal urban facilities.

LANGUAGES

It is obvious that the ability to speak the language of a country is a great asset, particularly for those in the more responsible positions on a party operating there. In countries where the language is particularly unfamiliar or difficult, such as the Eastern Areas, it is probable that most individuals will acquire only a limited, or at best, moderate, command of the language in a one or two year stay. However, a particular effort to learn as much as possible even in such cases should be made, as communications and operations through an interpreter are never fully satisfactory, and friendlier relations with the inhabitants are promoted by efforts to use their language.

A great deal of the foreign geophysical exploration for oil is done in Spanish-speaking countries and in such cases any person of ordinary intelligence should soon pick up a moderate knowledge of the language. It should be practically a requirement that in operations in the Latin-Americas those in responsible positions should be able to handle the language fairly well. Language barriers between the director of the party and his native labor may be a large negative factor in satisfactory operations. It may be observed in passing that the lisping Castil-

lian all too frequently taught in our American schools is not the Spanish spoken in the Spanish-Americas. Typical of the average American's knowledge of languages, and even that of the technical men who should know better, was that of a certain executive who thought his correspondence to Brazil should be written in Spanish.

PERSONNEL

The speed and success of practically any foreign geophysical program, regardless of the type, is largely determined by the character and quality of the personnel. Indifferent, trouble-making, or mediocre men on domestic projects can be replaced when desired, but these same individuals on a foreign project have a powerful advantage in the knowledge of the fact that their replacement would be a very slow and costly process and that their deserved summary discharge might possibly mean an indefinite suspension of operations. For this reason the personnel of any foreign party should be selected with the utmost care. If a choice should have to be made between character and ability the choice should lie with the perhaps slightly less capable individual who has demonstrated his dependability rather than a possibly more brilliant specimen who quits when conditions become tough.

Many formalities must usually be observed to secure admittance of the American personnel. Besides the usual passport, birth certificate, and medical requirements many countries now have a wide variety of restrictions on foreign technicians. Often it is necessary to show that the presence of any particular man is vital to the operation of the party.

If at all feasible the party chief of any geophysical crew, whether magnetic, gravimetric, or seismic, should have had previous foreign experience. While it is advantageous if the former experience has been in the same country, the next best substitute is experience under similar conditions. Only one who has previously met at least some of the different problems encountered under these circumstances can comprehend them. Difficulties with an unfamiliar language, arguing, cajoling, bluffing or somehow persuading a frequently indifferent or slow customs' office to permit the passage of equipment and supplies, handling inexperienced native labor, and looking after the health and well-being of party members are a few of the extra problems not generally encountered in routine domestic operations.

Geophysical programs, whether by contract or company crews, are usually conducted under the direction of the geological department of

the producing company. It frequently happens that the geologists, though entirely competent, are unfamiliar with the details and requirements of geophysical operations. Much friction between geological and geophysical departments, particularly in the case of non-company crews, can easily be aroused by a lack of cooperation or diplomacy. A studied policy on the part of the party chief and his personnel of carefully and fully explaining the reasons for the various activities and requirements of the geophysical operations is of the utmost importance. While it would appear that the necessity of such a course is obvious, examples to the contrary are all too frequent. Direction of the work by a geologist-geophysicist with experience in both fields offers much the best insurance of efficient and harmonious operations.

As previously stated, geophysical crews working abroad customarily operate with a minimum of trained American personnel. The lesser positions are usually filled by natives or other men picked up on the ground. Hence it is imperative that in the case of key positions such as instrument operator and geophysicist some other members of the crew should be competent at least to carry on their duties in cases of an emergency until a replacement can be secured. In the case of seismograph crews a radio man may be available to replace the regular operator or shooter. The assistant geophysicist should also be capable of substituting for the geophysicist, and in practice should and does carry on the routine interpretation and computing, thus permitting the geophysicist to devote most of his time to program planning and general administration, although at all times keeping a close check upon the interpretation.

In domestic operations on a seismograph crew the positions of party chief and geophysicist are sometimes filled by different men. However, for foreign work it is the very firm opinion of the writer that the functions of both must be handled by one individual for efficient operations. More or less routine details of field administration are quite properly delegated to the operator and of interpretation to the assistant geophysicist but the general authority should vest in one man. It is understood that the party chief has at least a working knowledge of the duties of each position on the party.

The operator should obviously be a man thoroughly familiar with his instruments, and should know not merely the routine operation of them but should be thoroughly conversant with their principles. He should be able to reconstruct from spare parts apparatus damaged or partially destroyed in the inevitable mishaps attendant upon work

under difficult conditions. His ability along this line may well mean averting a long and costly shutdown.

One of the most valuable men on any foreign crew and one now generally included in all personnel selections is the mechanic. He should be not only a good shop man, capable of handling the tools in a machine shop, but more important, should be a real "handy man" and able to perform a required job with the limited facilities usually available. On parties using automotive or marine equipment the mechanic is of course indispensable in keeping the equipment in operation. However, even with animal or manual transportation, there is a definite need for a good handy man. Personal evidence of the value of such a mechanic was afforded the writer on a mule-transportation seismograph project. Using only a breast drill and simple tools carried in his field kit a small makeshift lathe was constructed and repairs were made to a battery charging generator which saved an expensive shut down of two weeks.

Shooters on a seismograph party may at times be developed from natives, or found among the wandering American miners or construction men encountered everywhere, who have had experience handling dynamite. However, the policy of using trained men is decidedly preferable as so much of the safety of operations depends upon the powder man. Also, the frequent requirement that the shooter be able to operate radio equipment at the shot point generally rules out the untrained man.

Surveyors may be an actual part of the geophysical crew or may be detailed to it by the production company for which the work is being done. The former procedure is usually preferable as surveying should come directly under the authority of the party chief for most satisfactory results. It frequently happens that surveyors may be found locally, either from the natives or from the more or less itinerant American engineers. While these may be used to supplement the regular personnel the quality of work required usually demands the services of thoroughly reliable and competent surveyors. In the States with an established system of known boundaries and ties, a rather mediocre surveyor may perform the required duties satisfactorily enough. However, in the unsurveyed and sometimes unexplored areas covered in foreign operations a base system of coordinates and triangulation networks must usually be established upon which all subsequent locations are made. The astronomic and solar observations and the development of the grid system call for engineering information beyond that of the run-of-mine surveyor. The party chief should likewise

possess at least a working knowledge of the engineering requirements. In passing, it may be observed that the surveyor in some cases may have to be the hardest working man on the party.

While the foregoing remarks are somewhat more related to seismic personnel they are equally applicable to gravity meter and magnetometer men. The size, complexities and difficulties of operations with them are generally much reduced from those of the seismograph crew. However, the chief surveyor on a gravity meter crew will have heavier duties than his counterpart on a seismic party.

The old adage stating the harmful effect of "One bad apple in the middle of a barrel of good apples," may be strongly exemplified by the presence of one trouble-making individual on a party. The strain of operations under difficult conditions and uncomfortable living accommodations, constant annoyance by insect pests, and worst of all, enforced periods of idleness because of unfavorable weather conditions, will develop sharp edges in ordinarily congenial dispositions. The presence under those conditions of one disgruntled man desirous of promoting trouble may be the plague which changes an ordinarily cooperative crew into a bunch of discontented individuals and cliques. The trouble-maker may be in that frame of mind because of salary discontent, living or working conditions not as expected, or for any one of various reasons, the most frequent of which is apt to be jealousy of the more favorable position of some of the other personnel. While it may appear that excessive emphasis is placed upon this subject, the occurrence is so common and so serious that its importance can hardly be exaggerated. Except in serious cases, word of the friction rarely reaches the executive department back in the States, as the party manager is to a large measure forced to pass over and ignore unpleasantness in order to continue production. In ordinary circumstances in the States such a trouble-maker would be summarily discharged, but he knows, as well as the party manager, that the time and difficulty required for his replacement make that course practically impossible except as a last resort.

The question of the choice of personnel for a foreign party to operate under difficult conditions is a major executive problem. The character, demonstrated ability, and past record of the prospect are the major considerations. If he has weakened or quit under tough conditions before, the chances are good for a repetition of the act. Frankness as to conditions to be encountered is essential, for nothing angers the entire personnel so quickly as to find living and working conditions not as represented. If told before starting the job that it

will be difficult, that the camps will be remote, that weather and insects will be bad, and that recreational opportunities are practically non-existent, some prospects may refuse to go. Those who do accept, however, do so with an understanding of conditions and are much more apt to see the job through in a cooperative spirit.

Salaries for foreign operations are customarily substantially higher than for domestic work and include ordinary living expenses. However, the best attraction for the higher quality man is the promise of preferment in promotion either in remaining abroad or upon his return to the States after the completion of the foreign project. It is needless to say that such promises must be strictly kept because of future relations, if for no other reason.

The question of whether married or single men are to be chosen is a most vexatious one. While the single men have fewer home ties and can travel at will, the majority of the older and more experienced men required in the key positions are usually married. Unless living accommodations for the wives and children are available in a nearby city or permanent camp, their presence on a foreign party living in a field camp is most generally not feasible. Plain homesickness is the malady that has probably incapacitated more employees in foreign locations than any other disease. It is possible for a man actually to be sick, literally and physically from that cause, and if he has not gone that far then he may well have deteriorated greatly in his efficiency. Prevention of the occurrence is far the best cure. In the mild cases that practically everyone suffers at some time or other as sympathetic treatment as is feasible ordinarily succeeds best in the end.

Repeating previous statements, while only thoroughly competent men are sought for foreign assignments, the largest single qualification is the demonstrated character of the prospect. This is particularly true on the more difficult projects. Too many candidates for the positions are youngsters with ideas of romance, adventure, and travel. Actually, the romance is apt to be off-color, work and not adventure is the purpose of the job, and the travel portion is only incidental and eventually becomes tiresome, especially if done on one's own legs or the back of a hard-riding mule.

TRANSPORTATION, EQUIPMENT AND SUPPLY ORGANIZATION

The required method of transportation of geophysical instruments and equipment of course strongly influences their design. Since this last is a matter of individual company policy it is not discussed here

except as a by-product of the determining conditions. Transportation methods used abroad are the same as those for domestic use, the chief difference being that a much greater proportion of foreign work is conducted in isolated and difficultly accessible locations. Accustomed as is the average American to the all-weather highways of the States, it is difficult for him to realize the very primitive transportation conditions still existing in many of the foreign areas where oil exploration work is conducted. Even the old-time field man who has battled the swamps of the Mississippi delta country or the sand hills of West Texas is apt to find unaccustomed conditions and tougher situations. Moreover, he has to tackle them largely on his own initiative and without the assistance of the home office to whom he used to be able to turn for advice and aid. Emphasis in the following discussions is largely on those procedures normally unfamiliar to the domestic operator.

Operations will be conducted by the use of one or a combination of the following transportation methods: (1) Water, (2) Amphibious, (3) Automotive, (4) Animal, (5) Portage. Still in the future but well within the bounds of possibility are the conduct of certain types of geophysical surveys by the use of helicopters or low flying, slow speed airplanes.

(1) Water operations, outside of the fact that they are in a foreign area, are apt to be rather similar to those in the U. S., particularly the Mississippi delta area. The experienced Louisiana Gulf Coast operator has already met most of the technical problems associated with water work.

(2) Amphibious operations, and especially the type usually conducted with marsh buggies of various sorts, are also of the same general character as those in the States, especially in the Mississipi delta country and the Florida Everglades. However, an additional obstacle that frequently must be overcome in tropical and semi-tropical areas is the luxuriant, often impenetrable vegetation. Particularly in swampy areas the character of such growth is almost unimaginable to the inexperienced. As soon as they become available several of the amphibious vehicles developed for the army and navy, such as "ducks," "alligators," "weasels," etc. should prove of great assistance in much exploratory work.

(3) Automotive equipment of various types is the basis for most foreign geophysical operations as it is for domestic. Roads are usually few, trails are scarce, and most of the work is done cross-country, yet

the American-made cars and trucks stand up under the excessive punishment surprisingly well. An excellent object lesson in the requirements of sturdy transportation units was afforded by a certain European electrical party which came to Eastern Venezuela to conduct some experimental surveys in the same area over which American seismograph parties have been operating for several years. With their equipment carried by light European cars and trucks, only about two months of the rough, jolting usage were required to put their transportation units completely out of commission.

The question of the type of drive is usually decided by the companies' experience with analogous conditions. Multiple-axle and all-wheel drives are a necessity or a great help in many places. Balanced against that may be the difficulty or delay in obtaining repair parts in many areas, particularly under present conditions. In anywhere near normal times the larger U. S. auto and truck manufacturers maintain excellent service in the metropolitan areas of most countries. Even so, access to them may be very slow at times.

Seismic operations, and particularly the reflection method, normally require the use of drilled shot holes. Some American manufacturers have developed the truck transported shot hole drill to a state of perfection unapproached by foreign truck builders. Being much the heaviest automotive unit the drill trucks are the most apt to require extra driving mechanisms that may range all the way up to a crawler type tread. It is of interest to note that in some desert or semi-desert locations shot holes were in many cases left for water wells for the native population.

Considerable interest and discussion has centered about the utilization of "jeeps" for operations in tough areas. Their ability to operate under conditions beyond the capacities of any other motor-driven wheeled vehicle undoubtedly creates a very useful place for them. On the other hand, their extremely hard riding qualities find little favor with personnel for long continued, routine use. Also, the general and local availability of replacement parts represents another very severe problem for commercial users. Perhaps the truck manufacturers will develop a post-war vehicle based on their jeep experience that will incorporate all of its well known advantages and eliminate the most serious objections. On this subject of special carriers for difficult operations and terrain there may be added the rather obvious but frequently overlooked observation that where feasible it is often decidedly more economical and efficient to use the specialized vehicle

only on the job as required and to have conventional and/or lighter carriers available for personnel transportation to and from the location.

Because automotive equipment and installations are in general so standard with most exploration companies further comment is not believed required except to add that the installation of a good winch on practically every piece of equipment is one of the best investments that can be made.

(4) Animal transported equipment is used fairly frequently in areas too difficult for automotive equipment. It is the writer's opinion that it could probably be advantageously used at least in supplementary operations more frequently than is ordinarily done. Carts or wagons may be used if the country is fairly open or if passable trails already exist or can be cut without too much difficulty. Horses, mules, burros or oxen may be used to pull them. In a tropical environment, mules withstand climatic conditions and poor forage better than horses and are much faster than oxen. Moderately open and developed localities in Trinidad, Cuba and the Western Venezuelan llanos are known areas in which mule carts have been used for transporting geophysical instruments, supplies and camp equipment.

The design of geophysical instruments to be transported in carts ordinarily is little different from conventional truck-carried apparatus. Provisions to absorb the jolting due to the rough terrain usually traversed and the lack of springs in the carts is the main consideration. Small portable drills are made in sizes transportable in carts. They may be readily disassembled into parts of a size that can be handled without too much difficulty. Using 1″ drill rods and 3″ to 4″ bits they can produce 100 foot holes in reasonable time under ordinary drilling conditions.

Special provisions for developing seismograph records must be made when the conventional truck dark room is not available. The usual equipment consists of a portable case in which are fitted four covered cans containing the developer, fixer and two wash waters. This case is covered by a dark bag fitted with arm holes. All processes are done by feel, supplemented by timing. Under average field conditions where no temperature control is possible this requires quite a knack. However, it is one routine operation for which an intelligent native can ordinarily be trained.

There are many prospective areas where topography, terrain conditions, and vegetation are too difficult for the use of animal drawn

vehicles, but where they are not so extreme as to require porters. In such cases, which are encountered particularly in many of the Spanish-American countries, operations may be conducted with surprising speed and efficiency by the use of animal packed equipment. Although horses or burros are sometimes used, mules are ordinarily employed for, as previously stated, mules withstand difficult conditions better than horses. While burros have great resistance, due to their short legs they mire in the mud more easily than mules and are more apt to lose their footing while crossing rivers. Their load capacity and speed are also less.

A few fundamental principles govern the design of any equipment to be transported by pack mules (or other animals). The total load per animal should usually not exceed 200 pounds. This total must ordinarily be fairly evenly divided into equal loads on each side. Moreover, each of these should be of such a size and shape as will be best carried by the animal, and also be susceptible to quick and convenient packing and unpacking. It is with difficulty that one single, heavy load can be satisfactorily packed on one animal. The container cases must be adapted to the customs of the native animal handlers in the prospective country, for while it may appear far-fetched to design geophysical equipment to a size acceptable to some unknown, remote and obscure "mule-skinner" some thousands of miles away, the hard fact nevertheless remains that eventually native mule packers will have to be depended on to transport safely valuable and delicate instruments. In parts of Mexico, for example, *aparejos* or pack-saddles are ordinarily not used; instead, two thick pads laid across the animal's back receive the loads. These are fastened by separate cinches and ride high up on the animal's sides. The carrying cases are thus tilted at an angle of about 30 degrees from the vertical. This seemingly unimportant factor means that all equipment inside the carrying case must fit tightly and must not be injured by the tilting. Wet storage batteries, for example, must have a special suspension or support so they will remain upright. Further, the pack boxes riding on these pads have a very definite optimum size, which is determined by the size of the animal. Pack boxes about 10 inches wide, 18 inches deep and 24 inches long have been determined by long experience as being the most suitable size. This is approximately of the same dimensions as the ever-present gasoline or kerosene packing case holding two 5-gallon tins which is found everywhere, and which is much utilized by the natives. Thus by a seemingly roundabout and remote chain of circumstances there is determined the size and shape of a container which in turn places

the maximum limits of size, shape, and weight that must be approximately observed by the practical designer of geophysical apparatus. Articles that do not have to be packed in containers of course may exceed those pack box dimensions, as for example, tents, cots, etc.

Any attempt at an adequate discussion of the many problems involved in the design of equipment for an animal packed party is far beyond the scope of this discussion. That the instruments must be unusually sturdy and capable of withstanding severe and ordinarily unexpected shocks and treatment is an inescapable fact. Sometime during the course of an ordinary job it is a practical certainty that each and every piece of equipment will be bucked off of an obstreperous pack mule, dropped by a packer, and/or submerged while fording a river. Added to these are ordinary occurrences such as bumping packs against trees and rocks along trails, wetting by sudden rains when the pack covers are not in place, penetration by dust, and many other hazards that a geophysicist doing only routine work with truck equipment in the States can scarcely comprehend. Waterproofing and dust proofing in every possible manner is a constant objective.

Drilling equipment transportable by pack mules represents a further reduction in size and weight from cart or wagon equipment. Portable, knockdown, motor driven drilling equipment capable of 100 foot holes under ordinary conditions is available. The mud pump and engine usually constitute the heaviest and most awkward item to pack in pieces.

Transportation of camp equipment and living accommodations for the American and technical personnel, as well as that for the native labor, represents a very large problem. This may either be supervised directly by the party chief through his native foreman, or in conjunction with men from the geological staff who are apt to be accompanying the party. For example, consider a seismograph party that may be operating in one of the Latin-Americas. It will comprise about a half dozen members of the geophysical party proper, two or three engineers and geologists, a permit man familiar with both the ordinary natives and the various Indian groups, and anywhere from 20 to 50 or more permanent native laborers. Additional trail cutters, etc., may be picked up locally as the work progresses from one Indian village sphere to another. Even with each American's personnel effects limited to half of one standard size pack box, a cot and bedding, (no folding chairs, etc.) a very large number of pack mules is required to transport the barest essentials of apparatus and living accommodations. Counting saddle mules and those required for a four or five day

pack of dynamite from the end of truck transport, a total of 100 to 150 mules will be kept busy at all times. Supplying food and pasture for this many animals is in many locations an exceedingly difficult task.

(5) Portage of equipment becomes the last recourse as working conditions become too tough for other methods. A surprisingly large amount of geophysical and geological exploration has been conducted in this manner. The design of geophysical instruments that can be packed by porters is not very different from those that are to be packed on mules. If the topography and terrain are not too difficult a good, well fed porter can carry about 80 pounds although this figure may vary widely with the strength of the porter, terrain, climate, etc. Though a pack mule can carry 200 pounds, it must usually be distributed in two packs, one on either side, while with porters the single load may be almost half that. While bulky, heavy articles such as tents may be carried much easier in one piece by pack animals, it is evident that in case of necessity porters can transport the material for a geophysical program under any conditions where a man can walk or wade.

Areas in which porters rather than pack animals must ordinarily be employed are fortunately comparatively limited. Parts of the Latin Americas such as sections of the Barco area of Colombia, and parts of Borneo, Sumatra and New Guinea are some of the locations where geophysical work using this method is being or has been actively pursued. The usual reason why porters rather than animals must be used is that in some cases very thick jungle, bad swamps and standing water can be traversed only by men. In such areas, the number of combined porters and brush cutters has been reported to have reached 200 to 400 men for various crews. Even so, only the barest necessities for shelter and food would ordinarily be carried for the party, American and native alike.

Manually portable drills for shot hole drilling have been developed and are in use both abroad and in some of the very difficult areas of the United States, as the Mississippi Delta. These drills, and battery charging equipment, usually represent the heaviest and most bulky apparatus that cannot be conveniently disassembled further.

GENERAL EQUIPMENT AND PROGRAM

Although the design of specialized geophysical equipment will ordinarily represent the individual companies' modifications of present

instruments or developments based on them, both made in the light of expected conditions, a few extra comments are judged pertinent. The basic principle of equipment specifications for most foreign service is that it will probably undergo very hard usage under unusually difficult conditions where repair facilities may be scarce.Hence it should be as sturdy and simple as possible, and with all parts readily exchangeable and easily replaced when the inevitable deterioration or accident occurs. Closely paralleling this feature is the requirement that a complete stock of replacement parts and supplies adequate to meet practically any emergency should accompany the original equipment. To the writer's personal knowledge failure to do so caused one very expensive seismograph crew to sit idle one entire month.

It is obvious that the climate of the prospective territory is a major factor in the design of all equipment. The very humid conditions encountered in some areas require the use of special moisture-resisting seals wherever possible. Transformers, condensers, vibrators and many other parts quickly fail if not protected. In dry, extremely dusty areas such as many of the Near and Middle Eastern countries provision must be made as far as possible against the infiltration of fine dust particles which will penetrate the most minute openings. In tropical countries photographic supplies must be tropical-packed. Recording paper or film is packed in sealed foil containers which exclude air and dampness, and even the temperatures of 120°–140°F. frequently encountered have no immediate effects. Deterioration under these temperatures is more rapid, however.

The necessary tools for making any possibly required repairs on all equipment should of course be included. In a few instances shop facilities may be available near the scene of operations, but generally the whole range of repair work must be accomplished by the facilities at hand and the initiative and ingenuity of the party members. Selection of the tools should be done by the party mechanic and some individual familiar with conditions in the prospective country. In some instances it may be possible or preferable to purchase certain supplies in the larger cities of the prospective country. While an unduly burdensome amount of tools and repair parts should be avoided the supply must be adequate for any possible contingency. One single day's shutdown of operations may represent the loss of a greater sum than the cost of an entire stock of tools.

The entry of equipment and supplies into a foreign country is often a slow and difficult process. Under all circumstances it is a

task requiring a thorough knowledge of customs formalities and regulations. Ownership papers, as well as complete, detailed descriptions and specifications of all material are essential. In most ports of entry the services of Customs Brokers or Agents are practically essential for material accompanying the party, and particularly for subsequent shipments. These firms, which specialize in expediting the passage of goods through the customs in each direction have the information, experience and contacts required to secure reasonably prompt service. Export as well as import regulations add complications in most foreign countries. The spirit which apparently guides the actions of officials in that service in some localities may leave badly needed supplies lying untouched in the customs' warehouses for months unless convoyed through the maze of regulations by the brokers. The necessity for such a procedure is usually distasteful to the average operator but recognition of the situation is sometimes as essential as that of recognizing the futility of breaching a stone wall by repeated butts of the skull.

In many ways the planning, logistics and execution of a foreign oil exploration program closely resemble a military expedition, though the element of hostile resistance is absent except in relatively few places such as the Motilone Indian country along the Venezuela-Colombia border. The greatest difference is that the operating company must take account of expenditures, for if the company is to be able to remain in business income eventually must exceed outgo. With unlimited facilities and financial resources governmental operations may be conducted even under inefficient methods, but where a final accounting is required of a private business only capable efficiency is adequate to maintain and increase operations. Careful preliminary planning is a first essential to success and this requires adequate information upon all conditions and factors to be encountered so far as possible. The airplane has now shrunk the world into a small fraction of its former size and while actual travel and work upon the scene of operations may still be by laborious and even primitive methods much time and effort can be saved by air transport. The writer once spent nearly four weeks traveling over a route in the Spanish-Americas later jumped from end to end in one half day by air.

More and more it has become the practice for major companies to map their concessions first by air photos. The advantages of these maps are too well known to require much additional discussion or argument, although a few points are well worth repeating. In entirely

new country, which is only partially mapped or geologically reconnoitered, it is almost safe to say that no matter what the cost of aerial maps may be, it will be more than saved by the more efficient planning of subsequent geophysical operations. Unless an entire blanket geophysical coverage is intended, the aerial maps are used to determine locations of surface structures or suggestions of structures which thus furnish a starting point of operations. In a large and comparatively unknown concession this localization of effort may mean the difference between early successful results which will encourage the backers to further efforts, and abandonment of the program because random shots at such a big target failed to produce results in a short time. Moreover, the saving in the actual operations by planning them more efficiently from aerial maps is very great. Trails invisible on the ground can be spotted from air photos. The usual native guide is familiar only with his own locality and hence cannot compete with this source of information. The advantages of air photos for purposes of physical surveys, property, cultural and topographic determinations are well-known and highly important.

A final thought on a general philosophy of foreign exploration appears appropriate to close this discussion. With the exception of a few productive areas most foreign oil exploration will be conducted in localities relatively unexplored, both by previous geology and geophysics as well as the drill. Literally speaking, some of it will be truly unexplored! A well-integrated program of exploration thus becomes possible to the executives, by means of which cartography, geological data, and geophysical investigations may all be blended into one extensive, exacting but wholly fascinating procedure. The development stage is substantially that of the early days of the U. S. oil industry, but with all the knowledge, tools and facilities slowly gained over years of hard experience telescoped together for use. In his memorable discussion of the U. S. oil industry Mr. Wallace Pratt appropriately emphasized the apparently innate ability of Americans to find oil. This background of experience and "know-how," combined with unexplored oil resources abroad, can work together to produce a harmonious and profitable result to the mutual benefit of all parties concerned.

THE INTERPRETATION OF WELL SHOT DATA—II*

C. HEWITT DIX†

ABSTRACT

Five methods of shooting a well for the determination of vertical velocity, and the methods of reduction of the data, are discussed. Means are described for determining the existence of interference due to transmission of vibration down the cable which suspends the well geophone.

The primary purpose of shooting a well is to obtain information which one can use in conjunction with seismic reflection data to determine depths, dips, and horizontal offsets of subsurface reflectors. In some cases, a time-depth relationship can be used directly. For other purposes it is essential that a distribution of velocity with depth be obtained.

The present discussion covers the various procedures currently in use, together with a few new procedures. Additionally, we discuss the various difficulties encountered, including errors of interpretation and errors due to extraneous noise.

We may suppose at the outset that there are no actual mistakes in computations. Then the errors are normal observational errors which may in some cases be minimized by designing the observational procedure properly. We shall therefore be concerned with various methods of setting up in the field to shoot a well and with the various methods of interpreting the resultant data.

One result that should be emphasized is that the error is only partially dependent upon the error in measuring the travel time. A part of the error is due to the failure of our simplifying assumptions to correspond with the facts. Consequently, any information that we can obtain regarding the validity of our simplifying assumptions is information regarding a probable reliability of the final interpretation.

METHOD A

The usual method of shooting a well and of interpreting the data we shall call Method *A*. This consists of first correcting the directly read travel time to a datum at the shot point. These corrected directly read times are then reduced to vertical times by multiplication by the cosine of the angle between the shot point and the well mouth as seen from the geophone position in the well. Referring to

* Presented at the fourteenth annual meeting, Dallas, Texas, March 1944.

† United Geophysical Company, Pasadena, California.

Fig. 1, this angle is shown as angle A. This method is generally sufficiently accurate when the geophone depth exceeds the distance from the well mouth to the shot point. Otherwise, it may become very inaccurate indeed. The method is exact except for the error in reading the time on the record when the following conditions are satisfied: (a) the well is straight and vertical; and (b) the velocity is constant to the depth measured.

Naturally in case the velocity is constant the ray will be a straight line from the shot to the well geophone. In this case, Method A gives

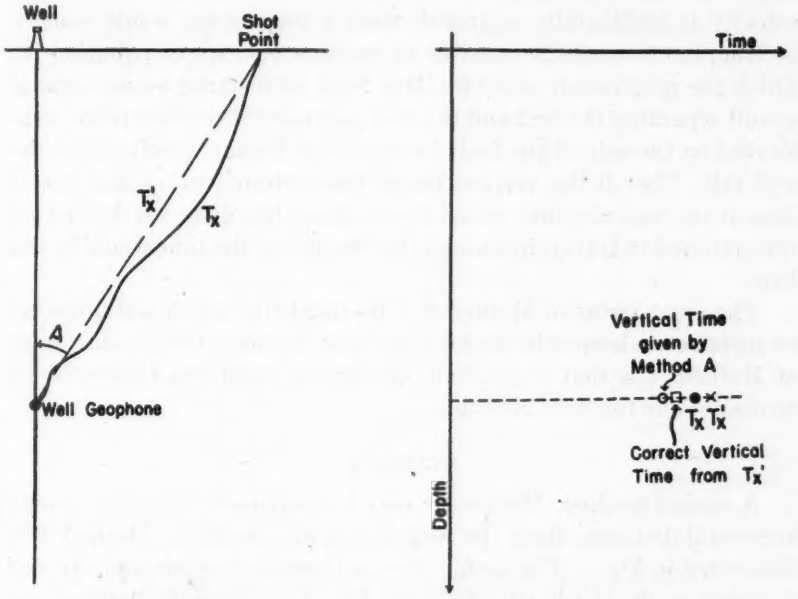


FIG. 1. Illustrating Method A for determining vertical velocity.

an accurate result. In case the velocity is not constant but is dependent upon the depth only, the actual ray will be different from the straight ray. Since the actual ray corresponds to a path of *minimum travel time*, the straight ray will correspond to a path of *longer travel time* and consequently the blind application of Method A will yield a vertical travel time which is too small. This is illustrated on the right hand side of Fig. 1 in which the cross is the time over the straight path and the square is the vertical travel time determined by using Method A and the time T_x' over the straight path. The observed time

T_x shows as a solid circle and the corrected vertical time based on this observed time is shown as the open circle. This open circle would be the value ordinarily given by Method *A*. Unfortunately, Method *A* itself gives no measure of the error involved by this procedure. Ordinarily this error is small enough so that it may be neglected.

Regarding Method *A*, we may state the following proposition: *If* the velocity is stratified horizontally; that is, is dependent only upon the depth *and* is not constant, *then* Method A gives vertical travel times that are too small. A somewhat more general proposition might also be considered by leaving out the assumption that the velocity is horizontally stratified. Such a proposition would usually be true, but it would be possible to devise a velocity distribution for which the proposition would be false. Such an instance would occur if a fault separated the well and the shot point and if the shot point were located on the side of the fault having much higher velocity than the well side. Then if the vertical travel time referred to vertical travel time at the well, the time would be too short, but if the vertical travel time referred to travel time under the shot point, the time would be too long.

The great virtue of Method *A* is its simplicity which will probably be sufficient to keep it in use for some time to come. The greatest fault of Method *A* is that it gives no information regarding observational errors not due to errors in timing.

METHOD B

A second method, Method *B*, may be employed when shot points at several distances from the well mouth are available. Method *B* is illustrated in Fig. 2. The profile view of three shot points and the well is shown on the left hand side of the Fig. The ray paths between the shot points and the well geophone are shown as straight lines. It is of course understood that these ray paths may not actually be straight lines. However, *if* the ray paths are straight lines we may plot the squares of the directly observed times (for simplicity assuming all shots fired at the datum) against the squares of the horizontal distances from the well to the shot points. This plot is shown on the right hand side of Fig. 2. *If* the velocity is constant and the rays are straight lines, *then* the points thus obtained will fall on a straight line. This straight line will intersect the t^2 axis at the point t_o^2 as shown. The positive square root of t_o^2 is the vertical travel time t_o.

Actually the ray paths will not be straight lines as indicated on the plate but will deviate somewhat from these straight lines. This deviation will show in the failure of the x^2, t^2 graph to be an exact straight line. Ordinarily, the graph as shown on the plate will be slightly concave upwards in case the velocity is stratified horizontally. In fact, we may state the following proposition: *If* the velocity is stratified horizontally and is not constant, *then* Method *B* gives a vertical travel time that is a little too large. Here I am assuming that Method *B* will be applied by fitting a straight line to the points of the x^2, t^2

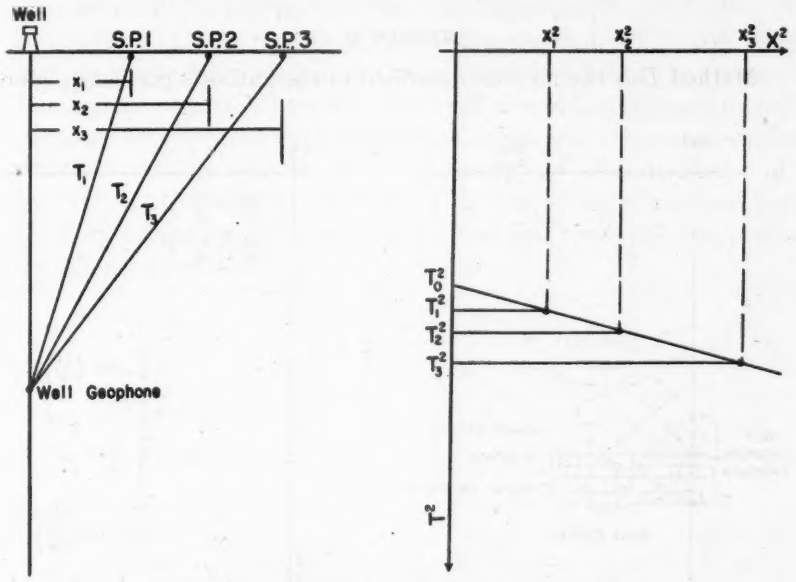


FIG. 2. Illustrating Method *B* for determining vertical velocity.

graph and that since the actual curve should be somewhat concave upwards, the straight line will cut the t^2-axis somewhat below where the true curved line would cut this axis.

This method is of some interest because it may furnish some information regarding the validity of our usual assumptions regarding velocity stratification. For example, if the x^2, t^2 curve is concave downwards, we can conclude that the velocity is not constant, and that it is not stratified horizontally. Here we are assuming, of course, that our errors in timing and in reading the times are small enough so that they will not invalidate our conclusion.

METHOD C

A third method, Method *C*, consists of applying Method *A* to each shot point distance where several shot point distances are available, and obtaining a reduced travel time which may be plotted for each depth against the shot point distance, x. A straight line fit to this set of points intersects the T axis at the point which approximately corresponds to the correct vertical travel time. This method will ordinarily correct the results given by Method *A*; it may in some cases tend to over-correct these results.

METHOD D

Method *D* is the method described in the author's previous paper

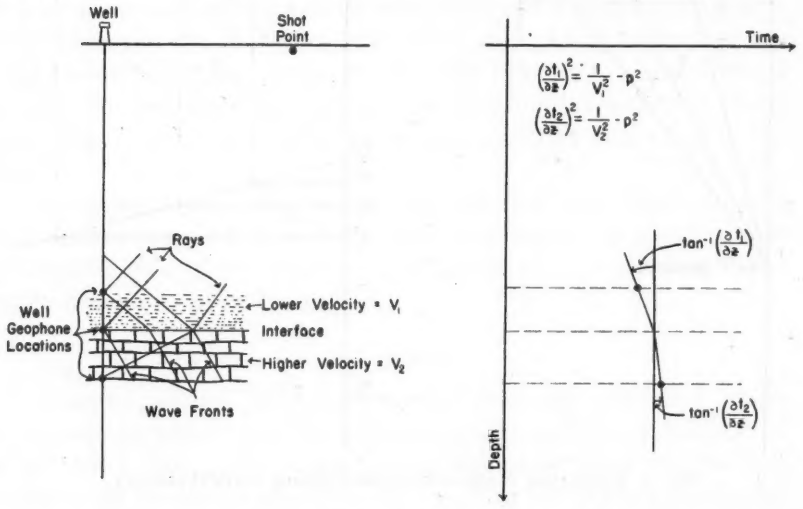


FIG. 3. Illustrating Method *D* for determining vertical velocity.

on the same subject.[1] Method *D* is somewhat more difficult to apply than the other methods but it has the virtue that it yields a velocity distribution which would yield the observed data if this velocity distribution were the actual velocity distribution. Method *D* is generally more accurate than the other methods even though it is dependent upon the determination of interval velocities. It can in fact

[1] GEOPHYSICS, Vol. IV, pp. 24–32 (1939).

be made as accurate as we please, excepting that the accuracy is always limited by the accuracy of reading the travel times.

Method *D* may be described by reference to Fig. 3. On the left side is shown the well, an interface between media of velocities V_1 and V_2, a set of rays, wave fronts, and three geophone locations in the well. Because of the bending of the rays at the interface, there is a sharp bend in the time-depth graph as shown on the right of the Fig. It should be emphasized that the times plotted on this time-depth graph are the directly read times assuming each shot at the datum. The slopes of the two parts of the time-depth graph are the two derivatives of directly read time, t, with respect to depth, z, one taken just above the interface and the other taken just below the interface. The first two equations on the right hand side of Fig. 3 show the relationships between the squares of these slopes and the corresponding velocities and the quantity p^2. This quantity, p^2, is a derivative of t with respect to horizontal distance. This derivative, p, may be eliminated by taking the difference between the first two equations to give the following equation:

$$\left(\frac{\partial t_1}{\partial z}\right)^2 - \left(\frac{\partial t_2}{\partial z}\right)^2 = \frac{1}{V_1^2} - \frac{1}{V_2^2} = \Delta' \text{ (measured)}$$

But

$$\Delta' = (V_2^2 - V_1^2)/V_1^2V_2^2 = \Delta V^2/\{V_1^2(V_1^2 + \Delta V^2)\}$$

where

$$\Delta V^2 = V_2^2 - V_1^2.$$

Hence

$$\Delta V^2 = V_1^4\Delta'/(1 - V_1^2\Delta').$$

Thus if V_1 is known and Δ' is measured, ΔV^2 can be found and hence V_2 can be found.

Method *D* is of greatest value for long offset shot points and for the part of the section shallower in depth than the shot hole offset distance. The advantage is especially noticeable when the variation of velocity in the upper section is large.

Method *D* will be in error if the velocity is not stratified horizontally or if the well is not sufficiently straight and vertical. In fact

if z' is the well direction, z is the true vertical, and n is the ray direction, then if ψ is the angle between n and z and ϕ is the angle between z and z' then

$$\frac{\partial t}{\partial z} = \frac{1}{V}\cos\psi, \quad p = \frac{1}{V}\sin\psi, \quad \text{and} \quad \frac{\partial t}{\partial z'} = \frac{1}{V}\cos(\psi - \phi)$$

or

$$\frac{\partial t}{\partial z'} = \frac{\partial t}{\partial z}\cos\phi + p\sin\phi$$

or approximately

$$\partial t/\partial z' = \partial t/\partial z + p\phi^\circ/57.$$

Hence the error made in taking $\partial t/\partial z'$ for $\partial t/\partial z$ is approximately $p\phi^\circ/57$. p can be estimated from $p^2 = 1/V^2 - (\partial t/\partial z)^2$ for the section in the well just above where the deviation from vertical becomes appreciable. Since p decreases continuously and slowly with increasing depth, we can estimate our error if we know the deviation from vertical ϕ° in degrees. Thus the fact that the well is not vertical can be taken into account in Method D if the deviations from vertical are known.

METHOD E

Another method of interpretation, applicable when velocity is stratified horizontally, utilizes the gradient of the travel time in the form

$$\left(\frac{\partial T}{\partial x}\right)^2 + \left(\frac{\partial T}{\partial z}\right)^2 = \frac{1}{V^2(z)}$$

where $T = T(x, z)$ is the travel time from a shot point at a distance x from the well mouth to a geophone at a depth z in the well. Fig. 4 illustrates the field setup for Method E. In this Fig. the well is located at W and the shot points used are s_1, s_2 and s_3. Since the velocity is assumed to be stratified horizontally, we may imagine that we have a shot point S in place of the well and three wells W_1, W_2 and W_3 in place of the three shot points. This exchange of shot point and well does not change the travel time when the velocity is stratified horizontally.

Method E was suggested in the first paper[3] but it was implied that the derivatives could be replaced by their corresponding difference qoutients. Such a replacement is not sufficiently accurate

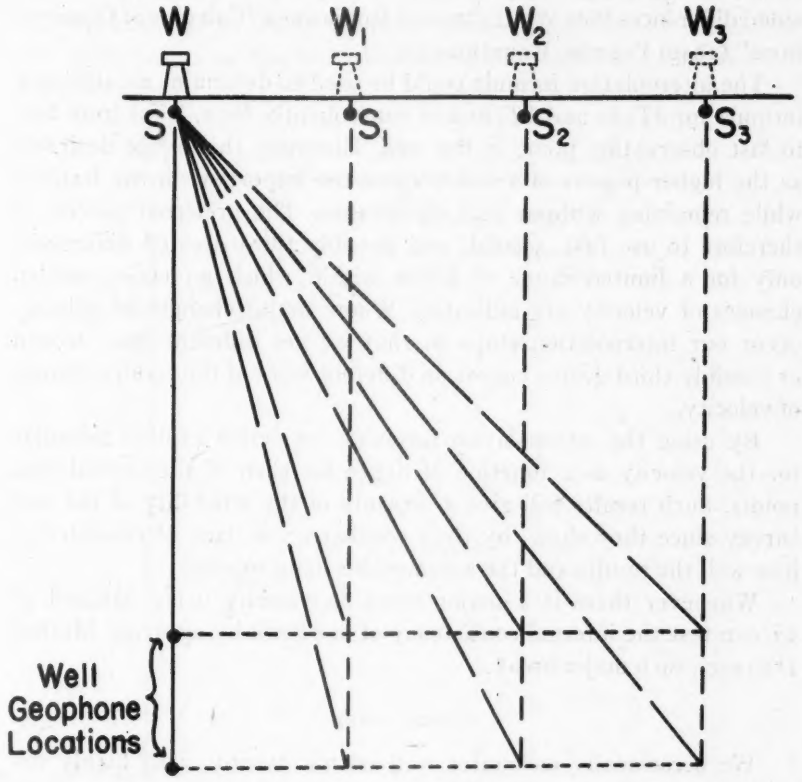


FIG. 4. Illustrating Method E for determining vertical velocity.

however. This is most evident in the calculation of $\partial T/\partial x$. Approximately, $T^2(x, z) = T_o^2(z) + k(z)x^2$ so that

$$\partial T/\partial x = kx/T = (\Delta T^2/\Delta x^2)(x/T)$$
$$= ((T_1 + T_2)/(x_1 + x_2))(x/T)(\Delta T/\Delta x)$$

where $\Delta T/\Delta x = (T_2 - T_1)/(x_2 - x_1)$. Hence unless x and t are carefully

[3] *Loc. cit.*

chosen $\partial T/\partial x \neq \Delta T/\Delta x$. However we avoid this difficulty if we use the formula $\partial T/\partial x = kx/T$ where $k = \Delta T^2/\Delta x^2$.

The best method of computing $\partial T/\partial x$ and $\partial T/\partial z$ appears to be to use the interpolation formulae for these derivatives in terms of divided differences (See Whittaker and Robinson's "Calculus of Observations" (1940) Page 66, Equation (4)).

The interpolation formula could be used to determine an algebraic formula for $\partial T/\partial x$ and $\partial T/\partial z$ and consequently for $1/V^2(z)$ from first to last observation point in the well. However, this is not desirable as the higher powers of z will become too important in the formula while remaining without real significance. The preferred process is therefore to use first, second, and possibly third divided differences only for a limited range of depth within which no major sudden changes of velocity are indicated. Where major changes of velocity occur our interpolation stops so that we get different first, second or possibly third degree curves on different sides of the sudden change of velocity.

By using the interpolation formulae we derive explicit formulae for the velocity as a function of depth for each of the several shot points. Such results will give a measure of the reliability of the well survey since they show, by their consistency or lack of consistency, how well the results and the assumptions hang together.

Whenever there is a major break in velocity using Method *E*, we can test the internal consistency of our work by applying Method *D* to each such major break.

CABLE NOISE

We occasionally encounter well seismic records with highly disturbing anomalous breaks When instrumental troubles are excluded there still remain the casing and the cable to give trouble. By pounding on the casing one can verify the already suspected very high velocity of elastic disturbances in the casing. However, if one clamps the cable with a suitable smooth and padded wooden clamp and strikes this clamp with a hammer while holding a geophone firmly against the clamp to record the instant of striking, one can record the arrival of the cable disturbance on the well geophone trace. Consequently the travel time down the cable is measured and the average velocity down the cable is calculated. This velocity in the cable is usually found to be between 8500 and 9500 feet per second.

The disturbance we usually observe travels with the cable velocity

in those cases where we have measured the cable velocity directly. This practically assigns the trouble to the cable. However further evidence can be obtained. Sometimes further evidence is really needed because the seismic velocities may be near the cable velocity and such that the cable kicks fall in with the seismic kicks so that one cannot tell which points on the time depth graph are seismic and which are due to the cable.

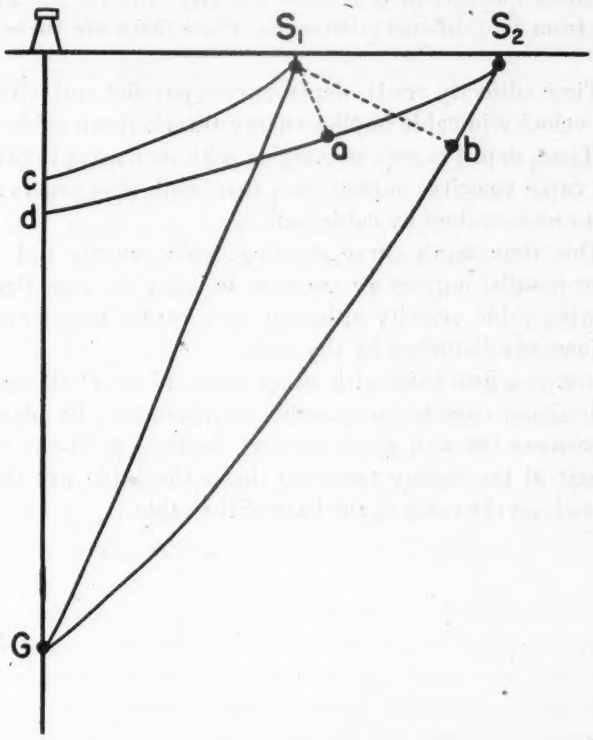


FIG. 5. Illustrating a field set up by means of which the existence of interference due to transmission of vibration down the cable may be established.

The field setup illustrated in Fig. 5 will make the detection of cable noise quite definite. In Fig. 5, s_1 and s_2 are two shot points and G is the geophone in the well. In case the disturbance travels down the cable it travels from s_1 to c to G and from s_2 to d to G. These paths may be reversed (for purposes of comparing travel times) in which case the difference of the two travel times is readily seen to be the travel

time from a to s_2. This time difference is clearly independent of the depth of the geophone G—as long as G is below d.

However if the paths are the desired geological paths $s_1 G$ and s_2bG then the difference of the two times is the travel time from b to s_2. Note that as G gets deeper bS_2 gets shorter. Also the time difference over bS_2 is shorter than the time difference over aS_2.

The process of detecting cable noise involves two precautions: (1) the direct measurement of cable velocity; and (2) the shooting of the well from two different distances. Then there are three possibilities:

(a) Time (directly read), depth curves parallel and with velocity same as velocity in cable implies energy travels down cable;

(b) Time, depth curves converging with increasing depth, neither showing cable velocity, implies data from both shot points is the desired data undisturbed by cable; and

(c) One time-depth curve showing cable velocity but the other curve not parallel implies we are safer in using the time-depth curve not showing cable velocity although both curves may correspond to travel times not disturbed by the cable.

We are on a firm basis with either cases (b) or (c) above.

Cable signal trouble can possibly be eliminated by placing a coil spring between the well geophone and the bottom of the cable. The major part of the energy traveling down the cable will then be reflected back up the cable at the base of the cable.

A NEW TYPE OF SEISMIC CROSS-SECTION WHEREIN ACCURACY OF REPRESENTATION IS RENDERED INSENSITIVE TO VELOCITY ERROR*

PHIL P. GABY†

ABSTRACT

A method is presented which was designed to:

1. Simplify computations in areas where velocity is known to vary, or may later be found to vary, laterally.
2. Considerably reduce the amount of recomputation necessitated by subsequent revisions in velocity.

The conventional time-section and time-map satisfy these requirements but are indicated generally to be subject to serious errors, as illustrated. The proposed system is explained and evaluated. Advantages believed to be peculiar to it are tabulated, and a practical method of plotting the cross-sections is presented.

NATURE OF THE PROBLEM

The fundamental variable used in reflection seismograph procedure is the interval of time required for the sound wave originated by a shot to reach a particular reflecting interface and return to the surface. This reflection time is of course measured along the slanting ray path from shot to actual reflecting point and back to the seismometer; the case of zero dip of the reflecting plane is merely a special case in which this path is essentially vertical. A reflection time observed by means of a single receptor, although accurately recorded, tells us nothing concerning the location of the reflecting point in space. In dip shooting we record on a single record a number of such single reflections from a particular velocity interface, assumed to be a geological contact, and from these determine the component time-slope of the interface in the direction of alignment of the recording instruments.[1]

From such a dip record we may readily determine the direction of offset of the reflecting point from the shot point, but in order to determine the amount of this offset we must have adequate knowledge of the velocity function pertaining to the particular region. Obviously, therefore, before representing seismic data on any cross-section or work map, we must choose one of two alternatives:

1. Adopt a velocity function which is assumed to be adequately accurate, or

* Presented at the annual meeting, March, 1944, Dallas, Texas.

† Geophysical Service, Inc., Dallas, Texas.

[1] In order to simplify discussion, it is assumed in this paper that the direction of profiling and of the resulting cross-section is that of maximum dip of the reflecting interface discussed. Through use of suitable precautions, the methods outlined may be applied to the general case where direction of profiling is oblique to that of maximum dip.

2. Assume, at least temporarily, that the offset of the reflecting point is zero.

It is customary procedure (although not universal practice) to apply a velocity function at an early stage in computation procedure in order to derive values for the horizontal offset and vertical depth of the reflecting point, and the angle of dip of the reflecting plane. Exact procedure varies, but substantially these values are used in constructing cross-sections and maps.[2] However, it is worthy of special notice that regardless of the particular computational system used to derive these values, the accuracy of representation on ordinary cross-sections and maps remains dependent upon the accuracy of the velocity function used in the computations.

The accumulation of well velocity data during recent years has demonstrated the presence of important lateral variations in velocity and the resultant fact that velocities obtained in any certain location should not be assumed valid over any large area. Variations of several per cent in the average velocity to a given depth have been noted in a lateral distance of only two or three miles. In dealing with such irregularities, interpolation and extrapolation of existing velocity control may be used in assigning velocity functions to specific areas. In this manner, large areas may be divided into several smaller areas, and a single velocity function may be assigned to each small area. An alternate practice has been to adopt a sliding scale of velocities so that velocity varies continuously with surface location as well as with depth. These and many other methods are useful in coping with the problem of lateral variations in velocity, but they are all in the nature of first approximations, and hence a certain amount of recomputation is frequently necessitated when additional velocity information is obtained.

Such recomputation could be greatly minimized by postponing the use of a velocity function until the late stages of computation procedure. Hence it might appear expedient to adopt assumption 2—that the offset of the reflecting point is zero. Unfortunately, this may lead to very confusing results in areas of deep folding, sharp folding at any depth, or faulted zones. The nature and causes of confusion are indicated by an actual case shown in Fig. 1 where comparative results are indicated when a given set of data is plotted under these two alternative assumptions. The syncline indicated by accurate com-

[2] E. D. Alcock, *Selection of Computational Methods for Seismic Paths*, GEOPHYSICS, Vol. VIII, No. 3, p. 297 (July, 1943).

putations appears as an anticline when horizontal offset is considered to be zero. Fig. 2, a companion to Fig. 1, illustrates a hypothetical geologic condition translated into corresponding reflection times and delta-times, which have in turn been plotted in accord with these two alternatives.

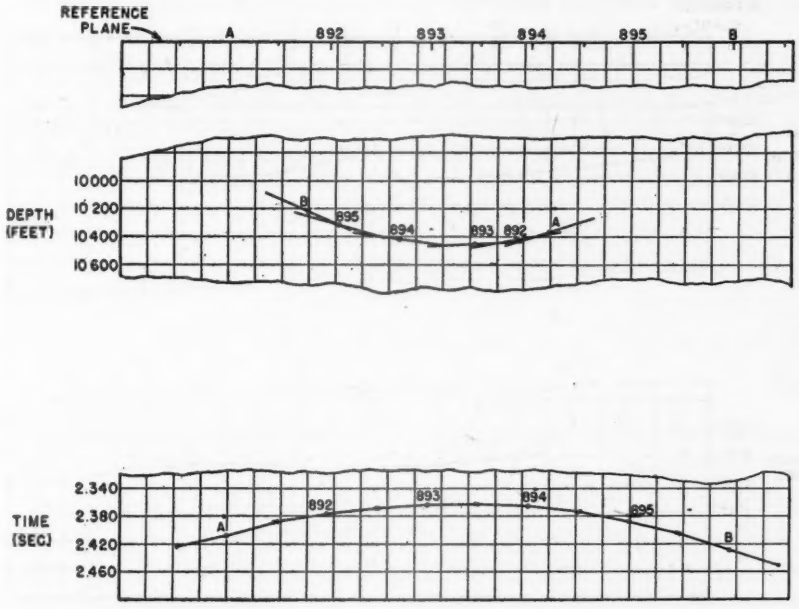


FIG. 1. A comparison to indicate the effect which may result from assuming zero offset. A single set of data is plotted, first with all reflections correctly offset (upper plot), and second as it would appear on a conventional time section wherein the offsets are considered to be zero. The example is based on data of high quality and the velocity function is essentially correct. The example represents an extreme case wherein a syncline appears to be an anticline if the offset of reflecting points be neglected.

It may be argued that such confusion does not occur in areas where dip is gentle, and that offset may safely be ignored in such areas. However, it is probably true that such action is dangerous because the distinction between areas where offset may be ignored and those where it may not be ignored is not one of sharp contrast as of black against white, but rather a differentiation between varying shades of gray. In order to avoid the confusion, then, it is usually necessary to compute the offsets before representing the data on either cross-section or map.

The prime problem is therefore one of finding a means whereby

necessary computations may be carried to an advanced point in such a manner as to be insensitive to velocity variations and errors. We desire to retain, in so far as possible, the orthodox time-section's insensitivity to velocity variation, but to combine with this feature the use of offset locations for all reflecting points. If this be possible,

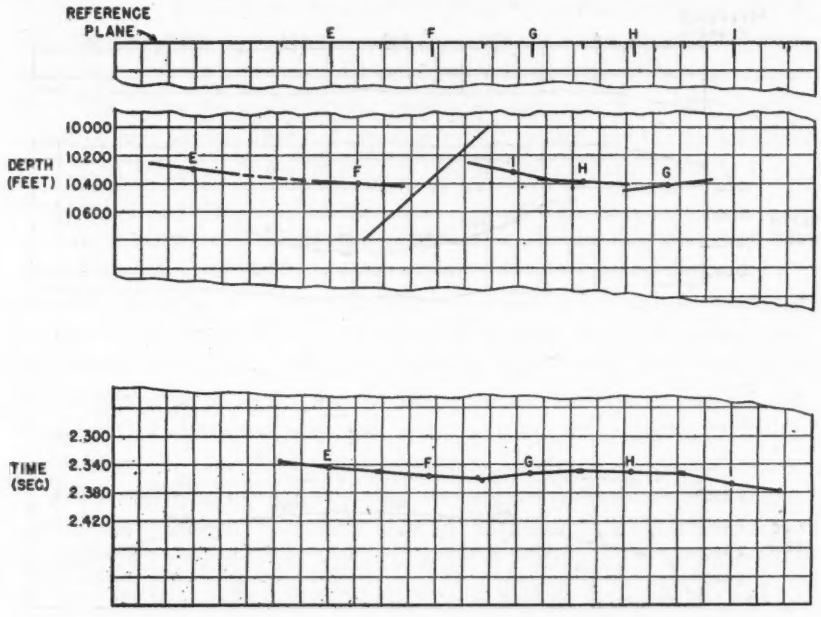


FIG. 2. A comparison to indicate the effect which may result from assuming zero offset. A single set of data is plotted, first with all reflections correctly offset, and second as it would appear on a conventional time section wherein the offsets are considered to be zero. This example, less extreme than the first, is based upon hypothetical data but illustrates how the use of correctly offset location for all reflecting points considerably simplifies identification and location of a fault.

then recomputations brought about by revision of velocity control can either be eliminated entirely, or at least greatly simplified.

THEORY

A satisfactory solution of the problem can be attained through use of a pair of coordinates for locating the reflecting point which will:

1. Considered as a pair, locate the reflecting point with an accuracy which is insensitive to nominal errors in velocity assumption,

2. Be suitably convenient for interpretive purposes.

A pair of coordinates which fulfills these conditions consists of:

1. Abscissa to be a continuous scale of horizontal distance, whereby the relative horizontal positions of all reflections and shot points may be accurately defined,
2. Ordinate to be vertical travel time from reference plane to any point on the cross-section.

Although the proposed scheme utilizes a velocity function to determine *both* coordinates, the accuracy of representation is extremely insensitive to velocity error, as is demonstrated in terms of a computational system in which

$$\theta = \sin^{-1} V_a \cdot \Delta T/\Delta X, \tag{1}$$

$$Y = \frac{V_a T_0}{2} \sin \theta, \tag{2}$$

$$T_v = T_0 \cos \theta, \quad \text{and} \tag{3}$$

$$\phi = \sin^{-1} V_i \cdot \Delta T/\Delta X. \tag{4}$$

The theorem herein advanced is simply that vertical travel time and offset, taken as a pair, vary little in comparison with modifications in the velocity applied. Vertical time assignable down to a reflecting horizon at a computed offset position remains within narrow limits the same for this particular offset position, even though a different velocity be applicable.

Fig. 3 is a diagrammatic representation of depth, offset, and dip values corresponding to a set of times observed on an instrument spread centered at O. The reflection time T_0 has been recorded by an instrument at the center, O, and across the total surface spread of instruments ΔX, an incremental time ΔT, produced by the dip of the reflecting bed, has been observed. Symbols used in describing this figure, and the mathematical relations, are defined below:

T_0 is observed zero spread travel time effective beneath reference plane.
V_a is average velocity first assigned to T_0.
D is depth of P, reflecting point first computed.
Y is horizontal distance by which P is offset from O.
θ is angle radius vector OP makes with the vertical axis.
ϕ is angle of dip of reflecting horizon as first computed.
T_v is $2D/V_a$, a vertical travel time associated with P.

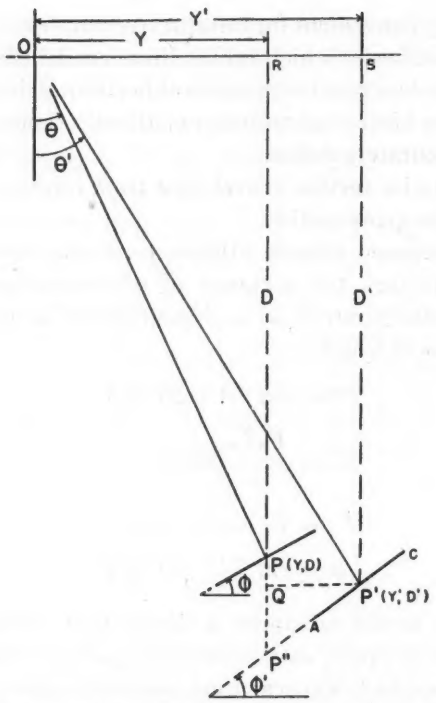


FIG. 3. Location of a reflecting point as determined by use of first one velocity, V_a, and then another velocity, V_a', with additional lines and points facilitating description of R.

V_i is terminal velocity in neighborhood of P.

D', Y', θ', ϕ', T_v', and V_i' are corresponding quantities related to P', the reflecting point as computed with the use of V_a', a different velocity.

T_v'' is $2RP''$ divided by the corresponding average velocity, V_a''.

V'' is velocity applicable in neighborhood of QP''.

N is ratio of V_i to V_a.

R is T_v''/T_v.

First, at P is shown the location of the reflecting point as computed with a velocity V_a. Then at P' is shown the location computed with a velocity V_a', proved at some subsequent date to be the true velocity pertaining to the location in question. In place of tan ϕ, Y, and D the new values are respectively tan ϕ', Y', and D'. Attention is here called to the fact that whereas coordinates of the reflecting point P as identi-

fied in this diagram are Y and D, and those of P' are Y' and D', the representation in the proposed coordinates would be Y and $2D/V_a$ or T_v for point P, and those for P' would be Y' and $2D'/V_a'$ or T_v'.

In this diagram the line AC represents the region of the bed over which the dip is actually measured by the record under discussion. It can be shown that P'', the vertical projection of P to AC or its extension, will fall between A and C for the large majority of cases encountered. To cover more extreme cases, it is necessary to assume the dip, $\tan \phi'$, to be uniform from P' to P''.

One can compute T_v'', the *true* vertical time assignable from the point R to the actual reflecting bed, even though the offset Y and the corresponding vertical travel time to P be originally computed with an erroneous velocity, V_a. Since the abscissa Y is held constant, the ratio T_v''/T_v is a measure of the error originally incurred beneath R through use of V_a instead of the correct velocity, V_a'.

Inspection of the diagram indicates that

$$T_v'' = 2RQ/V_a' + 2QP''/V'', \tag{5}$$

or that

$$T_v'' = 2D'/V_a' + \frac{2}{V''}[Y' - Y] \tan \phi'. \tag{6}$$

By using $2D/V_a$ for T_v one can write

$$\frac{T_v''}{T_v} = \frac{V_a D'}{V_a' D} + \frac{V_a[Y' - Y] \tan \phi''}{V'' D}. \tag{7}$$

The relations

$$D = \frac{V_a T_0}{2} \cos \theta, \qquad D' = \frac{V_a' T_0}{2} \cos \theta', \tag{8}$$

$$Y = \frac{V_a T_0}{2} \sin \theta, \quad \text{and} \quad Y' = \frac{V_a' T_0}{2} \sin \theta' \tag{9}$$

make simplification of this equation possible. For example,

$$Y'/Y = V_a' \sin \theta'/V_a \sin \theta. \tag{10}$$

From the definitions of θ and θ' it follows that

$$Y'/Y = V_a'^2/V_a^2, \tag{11}$$

whence

$$Y' - Y = Y \cdot \frac{V_a'^2 - V_a^2}{V_a^2}. \tag{12}$$

Substitution of Eqs. 8 and 12 into 7 yields the expression

$$\frac{T_v''}{T_v} = \frac{\cos\theta'}{\cos\theta} + \frac{V_a'^2 - V_a^2}{V'' \cdot V_a \cdot D} \cdot Y \cdot \tan\phi'. \tag{13}$$

Y/D may be replaced by $\tan\theta$ to give

$$R = \frac{T_v''}{T_v} = \frac{\cos\theta'}{\cos\theta} + \frac{V_a'^2 - V_a^2}{V_a \cdot V''} \cdot \tan\theta \cdot \tan\phi'. \tag{14}$$

Eq. 14 is the fundamental equation giving T_v''/T_v, a ratio now defined as R. Slightly different derivations of this ratio may be made through adoption of other computational systems, but the final value should be essentially the same so long as velocity error and dip are moderate.

Eq. 14, evaluating R, involves five independent variables: $\Delta T/\Delta X$, V_a, V_a', V_i', and V''. This number can be reduced in several ways. It may be assumed that the velocities concerned are repesentable in a practical manner by analytical functions providing a relation between V_a', V_i', and V''. On the other hand, purposes of this paper are met sufficiently well by use of the relation

$$V_i = N \cdot V_a. \tag{15}$$

If it is further assumed that V_i' is related to V_a' by the same numerical value of N and that $V_i' = V''$, the expression becomes

$$R = \frac{\cos\theta'}{\cos\theta} + \frac{V_a'^2 - V_a^2}{N \cdot V_a \cdot V_a'} \tan\theta \cdot \tan\phi'. \tag{16}$$

Implicit relationships in this equation make further reduction in the number of variables possible by considering V_a and V_a' collectively in the form of the ratio V_a'/V_a. N may in reality be a discontinuous variable, rather difficult—if not impossible—to evaluate exactly for individual cases; nevertheless the practical range of values of N is limited, and the effect upon R of reasonable variations is negligible so that precise evaluation of N is not required. The following tabulation for the extreme case of $\tan\phi' = 0.4$ indicates the effect:

N	R $(V_a'/V_a=0.94)$	R $(V_a'/V_a=1.06)$
1.20	.9927	1.0061
1.25	.9932	1.0056
1.30	.9938	1.0052

In either of these ways the list of independent variables may then be reduced so that R may be shown by a graph or a series of graphs. Eq. 16 will produce a slightly different graph for each distinct value

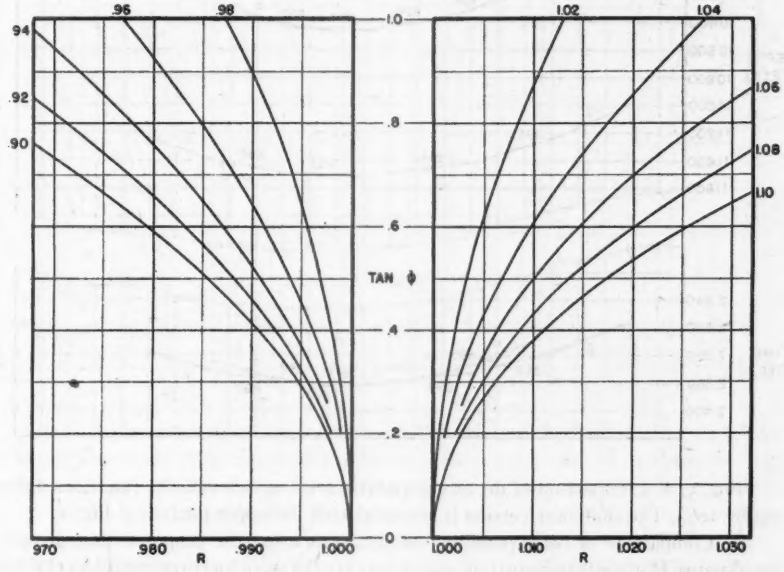


FIG. 4. A graph of R for the case where the ratio of terminal velocity to average velocity is 1.25. The ordinate represents dips computed incorrectly because of an erroneous velocity. The separate lines represent listed values of the ratio *revised velocity/erroneous velocity*. R is the factor with which incorrectly computed vertical travel times need to be adjusted.

of N. The one corresponding to N equal to 1.25 is given in Fig. 4 with tan ϕ, the computed dip, replacing tan ϕ' as an ordinate.

From a practical point of view we are not so much interested in the precise value of R, and in the small differences produced by variations in assumptions, as we are in one much more important fact: *the vast majority of seismic work is done under conditions such that, because of the magnitude of dip encountered, R varies from unity by only*

a few tenths of one per cent, even though the velocity function used in the computations be in error by several per cent. Variations of that order are at present less than the minimum error inherent in the recording, reading, and computing procedure.

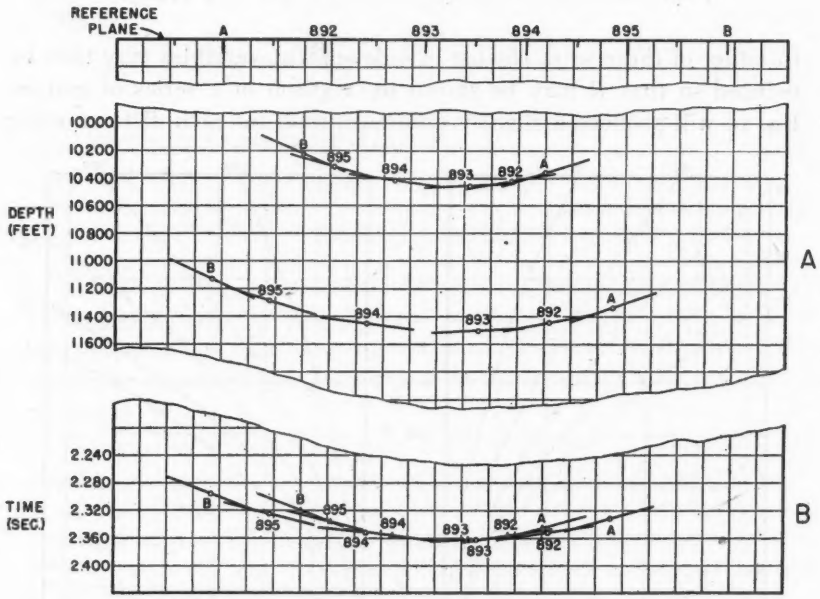


FIG. 5. A. Comparison of depth computations using two velocity functions differing by 10%. The shallower version is identical with the upper portion of Fig. 1.

B. Comparison of corresponding computations using the proposed time-distance coordinates. Horizontal offsets from shot points are the same for corresponding velocities as in A with vertical travel times represented as ordinates prior to adjustment by application of Fig. 4.

In other words, use of a velocity function which was in error by several per cent causes us to locate the reflecting point incorrectly, but the vertical travel time to the bed *at that point* on the map turns out to be essentially correct. Since this is true of any point, it is true of all points, and the original time horizon drawn on such a section is usually correct for practical purposes despite the error in assumed velocities.

Perhaps an actual example illustrating this result will serve to clarify matters. Fig. 5A shows two results of conventional plotting

of a single set of data. The topmost alignment represents use of an approximately correct velocity. Immediately below is shown the result of using a velocity function which differs from actual by approximately 10%. Fig. 5B shows the same comparison except that results have been plotted in the proposed coordinates. For the sake of clarity the incorrect results have in each case remained unadjusted in spite

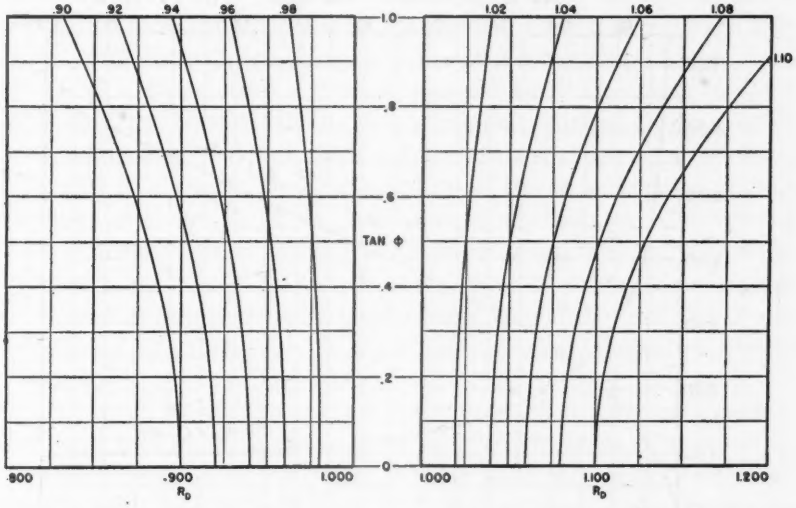


FIG. 6. A correction factor pertaining to adjustment of depths, rather than times, for errors in velocity function. Ratio of terminal to average velocity is taken as 1.25. R_d is plotted against incorrectly computed dips with separate lines for various values of the ratio V_a'/V_a. Compare with Fig. 4.

of the extreme dip, although it should be pointed out that the R values of Fig. 4 will largely eliminate even the minor discrepancies of the time section.

Fig. 6 shows graphically a correction factor, R_d, applicable to depth computations and corresponding to R in time computations. R_d as a function of V_a'/V_a and tan ϕ is expressed by the parametric equations

$$\sin \phi = V_i \cdot \Delta T/\Delta X \tag{17}$$

and

$$R_d = \frac{V_a'}{V_a} \cdot \frac{\cos \theta'}{\cos \theta} + \frac{V_a'^2 - V_a^2}{V_a^2} \cdot \tan \theta \cdot \tan \phi', \tag{18}$$

which is based upon an argument similar to that leading to Eq. 14. The factor is incidental to the purpose of this paper except insofar as Fig. 6 provides a very interesting contrast of magnitudes when compared with Fig. 4. Fig. 7 is a more analytical presentation which clearly indicates that a variation in velocity produces far greater variation

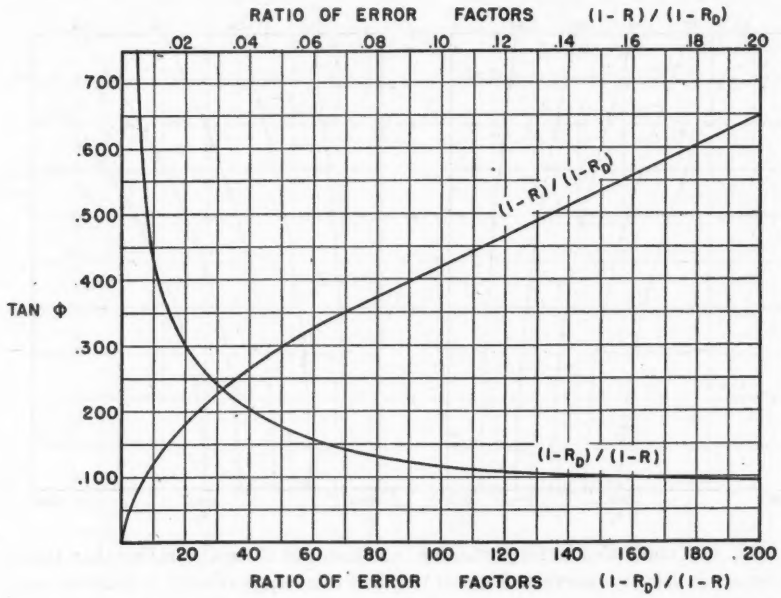


FIG. 7. This figure, derived from Figs. 4 and 6, represents an analytical comparison of the error produced by velocity variation upon a conventional cross-section with that produced on a cross-section based upon the proposed coordinates. Since $R \cdot T_v = T_v''$, it is obvious that R is a corrective factor and that $1-R$ is the corresponding error factor; similarly, $1-R_d$ is the error factor for the conventional depth cross-section. The ratio of these error factors indicates comparative errors inherent in the two types of cross-sections, provided equivalent scales have been used.

on the conventional depth section than it produces on a section plotted in the proposed coordinates.

APPLICATION

The original seismic data plotted upon cross-sections utilizing these coordinates will normally be of suitable accuracy, even though the velocity function available at that time should subsequently be found

somewhat in error. Recomputation and replotting will seldom be required since extreme cases—such as that in Fig. 5B—may be corrected directly on the map through use of a suitable graph of R.

From time sections, represented by Fig. 5B, one can make time maps on which would be contoured the vertical time from reference plane to horizon. Of course, if a single velocity function is believed to hold over the entire contoured area, then a single depth may be assigned to each time contour so that no more effort is involved than that normally required. However, the important thing is that since the map is based upon a type of cross-section that retains considerable accuracy despite velocity error, the time contours themselves are essentially correct even though different velocity functions pertain at different locations in the contoured area. Hence an accurate datum contour map can easily be derived even through use of a velocity function which varies laterally in a manner describable only by maps. Also any recomputation subsequently required can quickly be done because it is necessary to recompute *only* the depths, and this can be accomplished by multiplying listed times by half the corresponding velocities.

Although several computing procedures obviously are available for implementing the use of time-offset coordinates, the following procedure may be of interest in making practical use of the system, and in reducing the effort involved in the combined tasks of computing and plotting. This procedure eliminates chart reading, since with the use of T_0 and ΔT, adjusted in the usual way, one plots directly by tracing portions of a specially constructed chart. This chart, illustrated in Fig. 8, is probably best described as a wave front graph translated into (Y, T_v) space. This chart is based on the same computational system in which R was described—namely, that defined by Eqs. 1 through 3.

The arcs sweeping from left to right across the chart represent in terms of the chosen coordinates (Y, T_v) the position of the wave front at the various moments indicated. The curves radiating from O indicate various rays, each having a characteristic ΔT.

Since this chart has been constructed to give the offset and time values obtainable by direct computation, it follows from previous sections that the location of the reflecting point and the associated vertical travel time, taken as a pair, are correct within acceptable limits. However, we require verification that the time-dip obtained from such a chart is suitably accurate. The equation

$$\frac{dT_v}{dY} = \frac{2}{V_i} \cdot \frac{dD}{dY} \tag{19}$$

relates the wave slope in (Y, T_v) space to that in ordinary space, and precisely this same relation exists between correlation dips expressed in these two spaces. Correlation dip and spread dip given by wave slope in time space are therefore compatible to the extent that correlation dip is compatible with dip determined from a wave-front chart in ordinary space based on corresponding equations. Evaluation of the derivative of a wave front equation of this type in ordinary space,

$$\frac{dD}{dY} = \frac{\sin\theta \cdot \cos\theta}{\sin^2\theta - V_a/V_i}, \tag{20}$$

shows that within practical ranges of dip and of the ratio V_a/V_i,

$$\frac{dD/dY}{\tan\phi_d}$$

differs from unity by less than two per cent, which is ordinarily close enough for representation of spread dip attitude.

Hence, if the chart be made in scale to be used on the cross-sections, then it can be used as follows (See Fig. 8):

1. Using cross section tracing paper, slide the chart beneath the section and bring the two into register, with O on the chart being coincident with the intersection of reference plane and vertical line through the shot point from which the particular data at hand were obtained.
2. By means of T_0 and ΔT, locate the reflecting point; then place a pencil dot on the section at that point.
3. Through this point, draw a line representing a tangent to the imaginary wave that would, if drawn, have passed through the reflecting point.

These three steps represent the entire computing and plotting procedure beyond the customary steps of reading T_0 and ΔT from the record and adjusting these to a velocity reference level.

GENERAL CHARACTERISTICS

Briefly, characteristics of cross-sections plotted in space described by (Y, T_v) coordinates are:

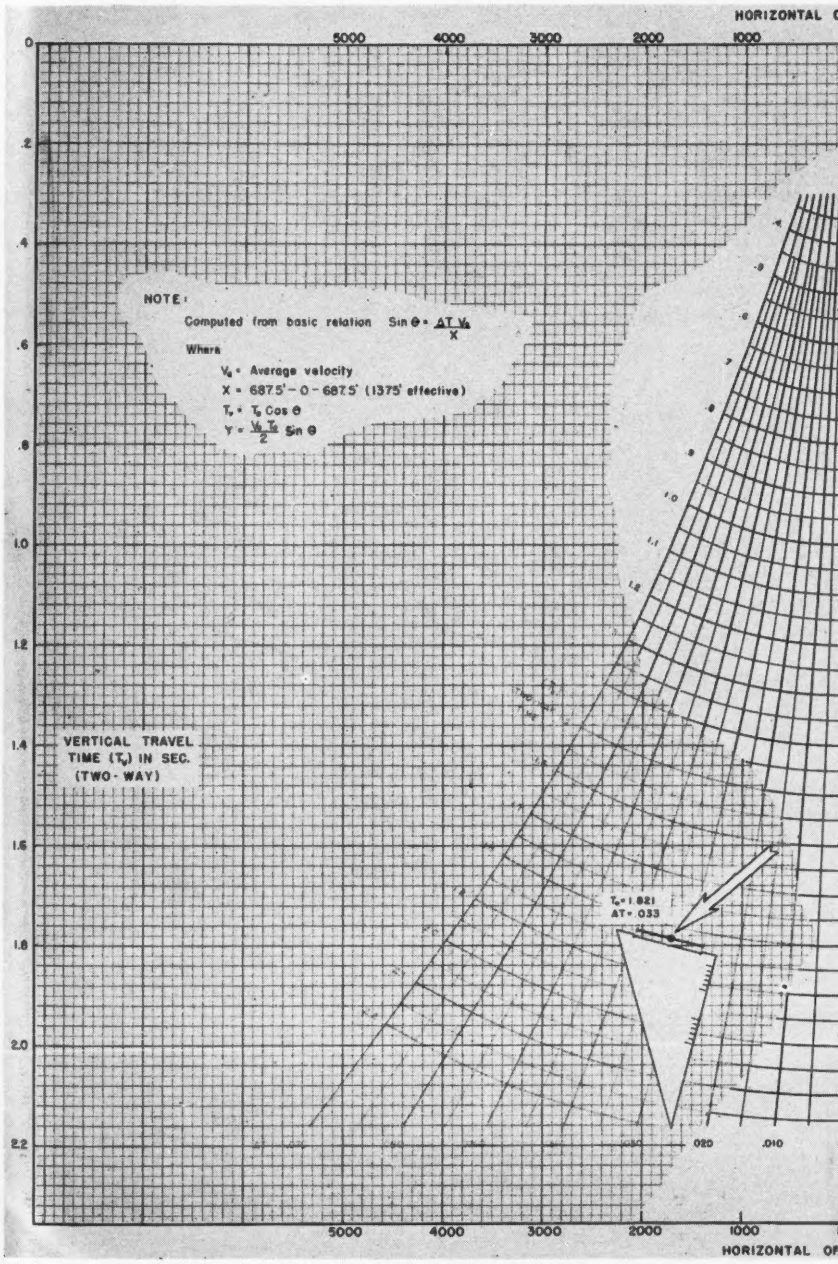
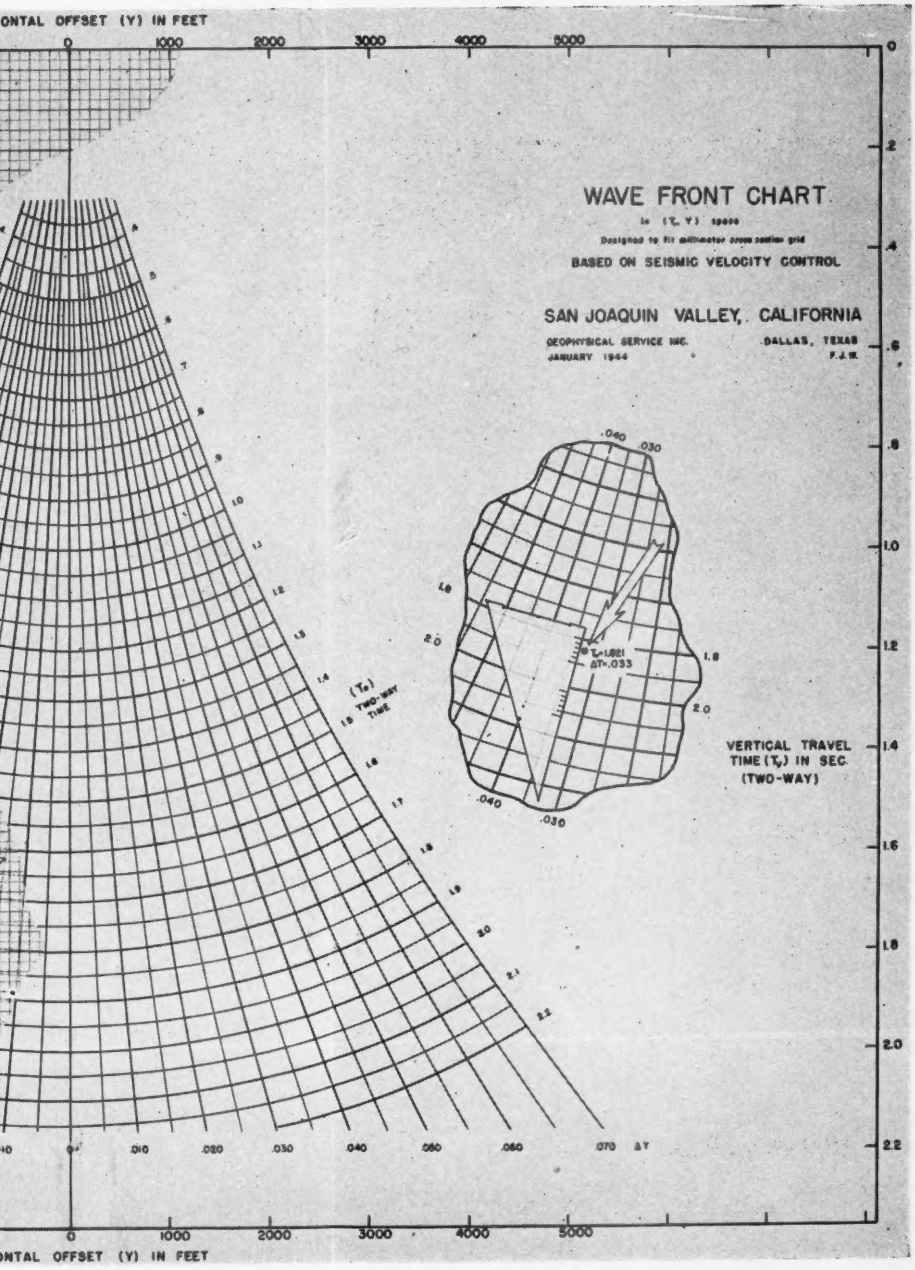


FIG. 8. A Wave-Front Chart in the proposed coordinate system based on the e
triangle, as well as the inset,



n the empirical computation system described. The superimposed cross-section grid and
e inset, show manner of plotting data.

1. Accuracy of representation is insensitive to nominal velocity error.
2. Use of a velocity function which varies laterally is simplified.
3. The method is readily adaptable to use of experimental wave front charts.
4. No distortion or error is produced not already inherent in the basic system of computations (see note below).
5. In routine use the system is at least as rapid as more conventional systems.

One limitation must be recognized: On ordinary cross-sections, where both coordinates are in feet, and where vertical and horizontal scales are identical, one could, if he chose, scale distances at any angle to the axes. However, with the vertical coordinate in vertical time and the horizontal coordinate in distance one can scale only parallel to one of the axes; i.e., time measured vertically, or horizontal distances measured horizontally. The scaled distance from origin to reflecting point, for example, is NOT the reflection time recorded on the record. Any attempt to measure obliquely on such a grid amounts to the assumption of a constant velocity determined by the choice of scales. However, there is no need to measure in slant directions, and inability to do so presents no handicap. The point merely needs to be kept in mind in building and using charts for plotting cross-sections in such coordinates.

ACKNOWLEDGMENTS

The author is indebted to Geophysical Service, Inc., for permission to publish this discussion. Appreciation is expressed to E. J. Stulken for suggestions and collaboration during later stages in the preparation of the paper and also to E. A. Kiesler, F. A. Hale, R. C. Dunlap, Jr., and others for various contributions.

THE ANALYSIS OF OBLIQUE REFLECTION DATA*

C. W. HORTON†

ABSTRACT

In regions where the reflecting layers have large dips it is difficult to interpret reflection data if the shot-point and the instrument-spread do not coincide. In this paper rigorous methods of locating the reflection-point and of determining the magnitude and direction of the dip are given. Two approximate solutions are discussed in detail and by means of theoretical considerations and numerical examples it is shown that the errors introduced by the approximations are adequately small.

PART I: THE PROBLEM

In some regions the geological formations have large angles of dip. In these areas it is not permissible to assume that the reflection-point is directly below the mid-point between the shot-point and the center of the instrument-spread. Since a rigorous analysis of such data is very laborious, it is desirable to know the accuracy of approximate solutions of the problem. In this paper one rigorous and two approximate solutions are discussed and the errors of illustrative examples are computed. Throughout the paper it will be assumed that the iso-velocity layers are horizontal, and, in consequence, that one-way travel-paths lie in vertical planes. It is also assumed that the velocity distribution is known.

It will be shown that when the geophones are arranged in a two-dimensional array such as a cross, one reflection is sufficient to determine the direction of propagation of the emergent ray and the total reflection time, T_r. If the shot-point and the instrument-spread are interchanged for a second measurement, more than enough data are available to locate the reflection-point and therefore checks on the accuracy of the measurements are possible.

Let i_0 be the dihedral angle between the earth's surface and the wave front of an incident plane wave. Two geophones that are in the plane of the earth's surface and separated a horizontal distance Δx along the direction of propagation will record the arrival of the wave with a time difference of, say, Δt, given by $(\Delta x/V_0) \sin i_0$. V_0 is the wave velocity in the consolidated material near the surface. Therefore as long as V_0 is constant, Δt is proportional to $\sin i_0$ provided that all of the Δt's be referred to the same Δx. $\Delta x/\Delta t$ is called the "apparent

* Manuscript received October 15, 1943.

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velocity" and has the following useful property. A vector parallel to the direction of propagation and whose magnitude is equal to the reciprocal of the wave velocity, has components in any rectangular coordinate system equal to the reciprocals of the apparent velocities along the respective coordinate axes. Thus if measurements of the Δt of a wave are made in two orthogonal directions on the earth's surface, they may be added vectorially to give a resultant vector Δt whose

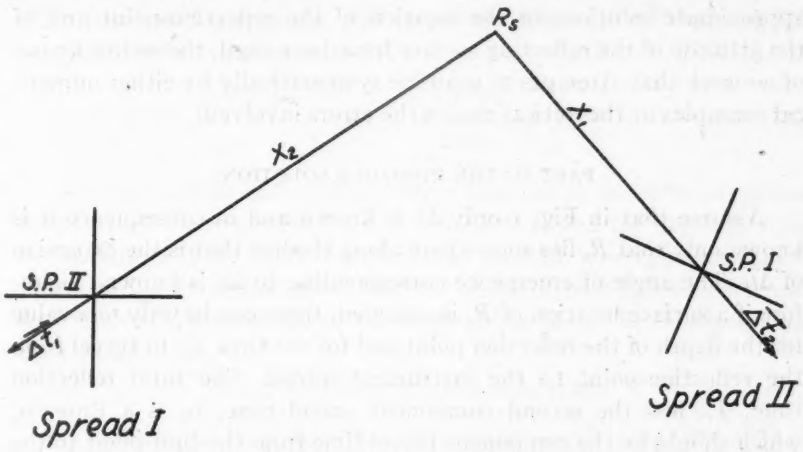


FIG. 1. Graphic solution of the migration of the reflection point when the path is traversed in each direction by interchange of spread and shot-point.

direction is the horizontal component of the direction of wave propagation and whose magnitude is $(\Delta x/V_0) \sin i_0$.

If one measurement is made between a shot-point and an instrument-spread and a second one is made with their positions interchanged, the reflection-point may be located by drawing the two instrument-spreads to scale as in Fig. 1. At each instrument-spread the component Δt's are added vectorially and the resultant vectors, Δt_1, Δt_2, are extended until they intersect at a point, R_s, which, since the rays are assumed to lie in vertical planes, must be the surface projection of the reflection-point. The horizontal components of the travel path can be measured. Since the velocity distribution is assumed to be known, for each horizontal distance and the corresponding angle of emergence there is only one depth of the reflection-point and one component travel time. The two depth values thus obtained

should be equal and the sum of the two component travel times should equal the reflection time, T_r. Any discrepancies can be smoothed out by adjustments in the position of R_s. A method will be given by which one can determine the direction and magnitude of the dip when the surface location and the depth of the reflection-point are known.

The use of two shot-points for one reflection-point is expensive and since the solution was over-determined, it seems possible that the problem can be solved with only one shot-point. Although many approximate solutions of the location of the reflection-point and of the attitude of the reflecting surface have been used, the writer knows of no work that attempts to examine systematically by either numerical examples or theoretical means the errors involved.

PART II: THE RIGOROUS SOLUTION

Assume that in Fig. 1 only Δt_1 is known and in consequence it is known only that R_s lies somewhere along the line that is the extension of Δt_1. The angle of emergence corresponding to Δt_1 is known. Therefore if a surface location of R_s is assumed, there can be only one value for the depth of the reflection point and for the time, τ_2, to travel from the reflection-point to the instrument-spread. The total reflection time, T_r, less the second component travel time, τ_2, is a time, τ_1, which should be the component travel time from the shot-point to the reflection-point. Thus when a location for R_s is assumed, values for the horizontal distance, x_1, the travel time, τ_1, and the depth, Z, of the first component of the travel-path, i.e. from the shot-point to the reflection-point, are determined. The correct location of the surface projection of the reflection point will be found when these three values are consistent. Thus the solution of the oblique incidence problem is possible by means of a trial and error process. In order to be rigorous one should prove that a unique solution results from this process, but for a reflecting surface with a dip of less than 90° the uniqueness of the solution is obvious from physical intuition.

When the reflection-point, R, is located, the entire path of the ray is known. Consequently the angles with the vertical, i_ξ, of the incident and i_η, of the reflected rays are shown. These angles are illustrated in Fig. 2. Triangles PRB and RPA are constructed (see Fig. 2) in the vertical planes of the incident and reflected rays so that

$$\angle BRP = i_\xi, \qquad \angle PRA = i_\eta.$$

Then

$$PB = Z \tan i_\xi, \qquad PA = Z \tan i_\eta.$$

The surface line AB is constructed and divided at a point N such that

$$\frac{AN}{NB} = \frac{\cos i_\xi}{\cos i_\eta}. \tag{1}$$

The directed line segment $\overline{PN}$ is the direction of the dip, and the magnitude of the dip, α_t, satisfies

$$\tan \alpha_t = \frac{PN}{Z}. \tag{2}$$

In this solution the trial and error location of the reflection-point is done best with the aid of a wave front chart and the determination of the dip is done easily by graphical construction. The method is practical but laborious. So far as the writer knows this solution was first derived by members of the staff of the Shell Oil Company, Incorporated.

PART III: APPROXIMATE SOLUTIONS

It is desirable to introduce a concept which will be called that of the normal Δt. A logical definition for the normal Δt is: "The normal Δt for a given arrangement of shot-point and instrument-spread and for a given velocity distribution is the Δt (defined above) that would be observed if a horizontal reflecting plane existed at the same depth as the reflection-point of the reflection with which the normal Δt is to be compared." This will be denoted $\Delta t_N{}^{(1)}$.

Although this definition is suitable for the purpose of analysis, it is not an observable quantity and therefore it should play no part in the theory of reflection shooting.

A second definition of the normal Δt, $\Delta t_N{}^{(2)}$, can be made in terms of observable quantities. "The normal Δt for a given arrangement of shot-point and instrument-spread and for a given velocity distribution is the Δt that would be observed if a horizontal reflecting surface existed at such a depth that the total travel time for a reflection from it is equal to the total travel time of the observed reflection with which the normal Δt is to be compared."

For the conditions encountered in practice these values do not

differ greatly. The second is always slightly smaller. In the analysis $\Delta t_N^{(1)}$ will be used, but in the numerical examples both values will be used to show the resulting difference. The travel-paths which give normal Δt's, $\Delta t_N^{(i)}$, will be called "normal travel-paths."

It is desirable to clarify two concepts that may cause confusion. The notation Δt is being used to designate the difference in the arrival times of an incident plane wave as determined at two geophones separated a distance Δx. For the particular case of reflections from a horizontal interface, this time difference is sometimes called the "step-out time," and so the time intervals defined as normal Δt's could properly be called step-out times. However, since the property of chief interest in the normal Δt is that it is a vector whose magnitude is proportional to the sine of the angle between the vertical and the normal to the wave front, the terminology "normal Δt" will be retained.

Throughout the remainder of this paper "R" will be used to denote the true reflection point and "P" will be used to designate the surface projection of R. However, to avoid circumlocution both R and P will be referred to as the reflection point.

In the rigorous solution the position of R is first determined and then the direction and magnitude of the dip are determined. However, if the location of the reflection point, R, has been accurately found, it is possible to determine the direction and the magnitude of the dip by an approximate method. The validity of this approximation is demonstrated both analytically and numerically.

Even if the rigorous solution is modified by means of these shortcuts, the computations remain laborious. In routine interpretation it is desirable to use a method that involves only a small amount of computation. The following is an approximate solution that has been frequently applied: vectorially subtract the normal Δt from the observed Δt and then treat the resulting vector as the Δt for a normal incidence reflection referred to the midpoint between the shot-point and the instrument-spread. It is shown by theory and by numerical examples that the resulting direction of dip is accurate within allowable limits. It is shown by numerical examples that the errors in the magnitude, and in the location and the depth of the reflection-point, R, are adequately small.

In the numerical examples fifty reflection points were chosen on one half of a horizontal plane at a depth of 6,000 feet. For the velocity distribution of

$$V = 5{,}400\left\{1 + \frac{Z \text{ feet}}{12{,}000}\right\} \text{ feet/sec.}$$

the true direction and magnitude of the dip corresponding to a reflection from each point was computed.[1] Using the observable quantities corresponding to each reflection point the unknowns were recomputed by means of the various approximations. The errors are contoured so that the regions of validity are immediately obvious. This analysis is made for a separation of 2,000 feet between shot-point and instrument-spread.

PART IV: DETAILED ANALYSIS

A. LEMMA

For a linear velocity distribution

$$V(Z) = V_0\left(1 + \frac{Z}{L}\right)$$

we have

$$x = L\left\{\frac{\cos i_0 - \cos i}{\sin i_0}\right\} \tag{3}$$

where V_0 = velocity at the surface
$V(Z)$ = velocity at depth Z
x = horizontal component of distance travelled
i_0 = angle with the vertical at surface
i = angle with the vertical at depth Z

Eq. 3 may be solved to yield

$$\sin i = \frac{\lambda\left(\frac{x}{L}\right)}{[A(x)^2 - \lambda^2]^{1/2}}; \qquad \cos i = \frac{\lambda^2 - A(x)}{[A(x)^2 - \lambda^2]^{1/2}} \tag{4}$$

where

$$\lambda = \frac{V(Z)}{V_0} > 1, \qquad A(x) = \frac{1}{2}\left[\left(\frac{x}{L}\right)^2 + \lambda^2 + 1\right]$$

[1] See Fig. 13 for contours of the true magnitude of dip to give a reflection from shot point to instrument-spread 2000 feet away.

From the first of Eqs. 4 it can easily be shown that

$$\left\{\frac{\sin i_y}{y}\,\frac{x}{\sin i_x}\right\} = 1 + \frac{\lambda^2+1}{(\lambda^2-1)^2}\,\frac{(x^2-y^2)}{L^2} + \frac{1}{2L^4(\lambda^2-1)^4}\left\{y^4[3(\lambda^2+1)^2-(\lambda^2-1)^2] + x^4[(\lambda^2-1)^2-(\lambda^2+1)^2] - 2(\lambda^2+1)^2x^2y^2\right\} + O\left(\frac{x,\ y}{L}\right)^6.$$

This series converges for values of x and y less than 0.4L and for $\lambda^2 \geqq 2$. For the actual range of values experimentally encountered the series may be well approximated by

$$\frac{\sin i_y}{y}\,\frac{x}{\sin i_x} \simeq 1 + \frac{\lambda^2+1}{(\lambda^2-1)^2}\left(\frac{x^2-y^2}{L^2}\right) \tag{5}$$

if

$$\left.\begin{array}{c} x,\ y \leqq 0.4L \\ \lambda^2 \geqq 2 \end{array}\right\}. \tag{6}$$

B. SHORT CUT TO THE RIGOROUS SOLUTION

Throughout this paper the following symbols shall have a constant meaning (see Figs. 2 and 3).

β_t = true direction of dip referred to the $-x$ axis
$\beta_a^{(i)}$ = approximate direction of dip referred to $-x$ axis determined by $\Delta t_N^{(i)}$ ($i = 1$ or 2)
β_r = direction of line segment PO referred to $-x$ axis
α_t = true magnitude of the dip
P = surface location of the reflection point
S = shot point
I = center of instrument-spread
$\xi = \overline{SP}$
$\eta = \overline{IP}$
i_ξ = angle of the incident ray with the vertical at R
i_η = angle of the reflected ray with the vertical at R
$i_{0\xi}$ = angle of the incident ray with the vertical at S
$i_{0\eta}$ = angle of the reflected ray with the vertical at I
Z = depth to R

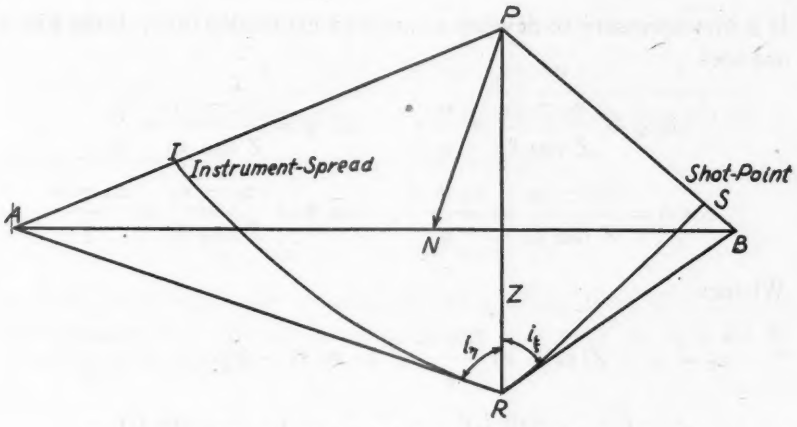


FIG. 2. Three dimensional view illustrating the solution for direction and magnitude of dip.

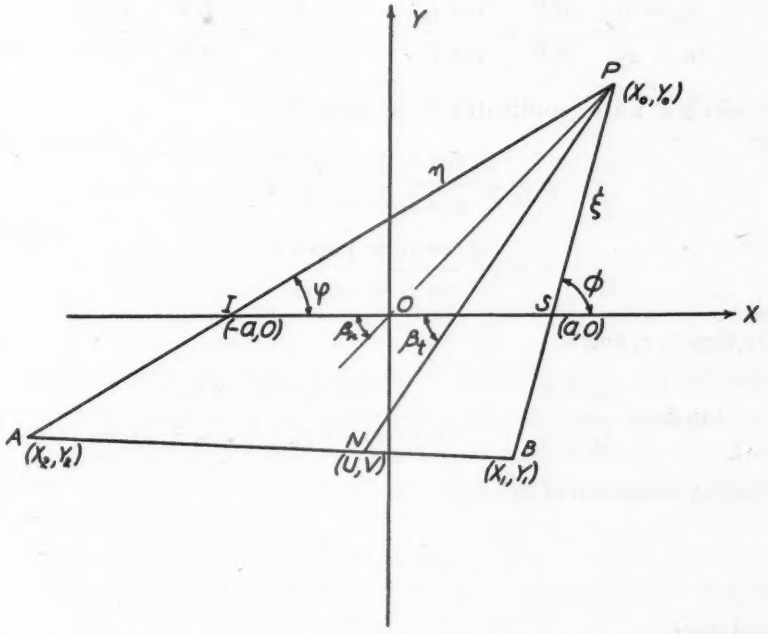


FIG. 3. Shot Point *S*, Instrument spread *I*, Reflection Point *P*, and auxiliary constructions located on Cartesian coordinates.

It is first necessary to develop an analytic expression for β_t. From Fig. 3 one sees

$$\sin\phi = \frac{y_0 - y_2}{Z\tan i_\eta} = \frac{y_0}{\eta}; \quad \sin\Phi = \frac{y_0 - y_1}{Z\tan i_\xi} = \frac{y_0}{\xi}$$

$$\cos\phi = \frac{x_0 - x_2}{Z\tan i_\eta} = \frac{x_0 + a}{\eta}; \quad \cos\Phi = \frac{x_0 - x_1}{Z\tan i_\xi} = \frac{x_0 - a}{\xi}$$

Whence

$$\left.\begin{aligned} x_2 &= x_0 - Z(x_0 + a)\frac{\tan i_\eta}{\eta}; \quad x_1 = x_0 - Z(x_0 - a)\frac{\tan i_\xi}{\xi} \\ y_2 &= y_0\left\{1 - Z\frac{\tan i_\eta}{\eta}\right\}; \qquad y_1 = y_0\left\{1 - Z\frac{\tan i_\xi}{\xi}\right\} \end{aligned}\right\}. \quad (7)$$

One also has from Eq. 1

$$\frac{x_1 - u}{u - x_2} = \frac{\overline{BN}}{\overline{AN}} = \frac{\cos i_\eta}{\cos i_\xi}; \quad \frac{y_1 - v}{v - y_2} = \frac{\overline{BN}}{\overline{AN}} = \frac{\cos i_\eta}{\cos i_\xi}$$

in which u, v are coordinates of the point N.
or

$$\left.\begin{aligned} u &= \frac{x_1\cos i_\xi + x_2\cos i_\eta}{\cos i_\xi + \cos i_\eta} \\ v &= \frac{y_1\cos i_\xi + y_2\cos i_\eta}{\cos i_\xi + \cos i_\eta}. \end{aligned}\right\}. \quad (8)$$

By Eqs. 2, 7, and 8

$$\tan\beta_t = \frac{y_0 - v}{x_0 - u} = y_0\frac{\sin i_\xi/\xi + \sin i_\eta/\eta}{(x_0 - a)\sin i_\xi/\xi + (x_0 + a)\sin i\eta/\eta}.$$

Now by definition of β_r,

$$\tan\beta_r = \frac{y_0}{x_0},$$

and since

$$\tan(\beta_t - \beta_r) = \frac{\tan\beta_t - \tan\beta_r}{1 + \tan\beta_t\tan\beta_r},$$

one finds

$$\tan(\beta_t-\beta_r)=\frac{ay_0\{1-(\xi\sin i_\eta/\eta\sin i_\xi)\}}{(y_0^2+x_0^2-ax_0)+(y_0^2+x_0^2+ax_0)(\xi\sin i_\eta/\eta\sin i_\xi)}.$$

In the numerator, by virtue of Eq. 5, one can put

$$1-\frac{\sin i_\eta}{\eta}\frac{\xi}{\sin i_\xi}\simeq-\frac{\lambda^2+1}{(\lambda^2-1)^2}\frac{1}{L^2}(\xi^2-\eta^2)$$

In the denominator the presence of the additive term $y_0^2+x_0^2-ax_0$ obviates the need for the correction term and so $(\xi\sin i_\eta/\eta\sin i\xi)$ is set equal to one. Hence

$$\tan(\beta_t-\beta_r)\simeq\frac{\lambda^2+1}{(\lambda^2-1)^2}\frac{1}{L^2}\frac{ay_0(\eta^2-\xi^2)}{2(x_0^2+y_0^2)}.$$

Now

$$\eta^2=y_0^2+(x_0+a)^2;\qquad \xi^2=y_0^2+(x_0-a)^2$$

and so

$$\eta^2-\xi^2=4ax_0.$$

By changing to polar coordinates

$$r=[x^2+y^2]^{1/2};\qquad \theta=\tan^{-1}(y/x)$$

one has

$$\tan(\beta_t-\beta_r)\simeq\frac{\lambda^2+1}{(\lambda^2-1)^2}\frac{a^2}{L^2}\sin 2\theta. \tag{9}$$

Thus if, after the reflection point P is determined, the direction of the dip is taken to be the radial vector $\overrightarrow{PO}$, the error depends only on the direction of the dip and not on its magnitude (provided of course conditions (6) are satisfied). In particular, the error is a maximum for

$$\theta=\frac{\pi}{4}+n\frac{\pi}{2}.$$

If $\theta=\dfrac{\pi}{4}$, $\max\tan(\beta_t-\beta_r)\simeq\dfrac{\lambda^2+1}{(\lambda^2-1)^2}\dfrac{a^2}{L^2}$.

As a numerical example, take $\lambda=1.5$, $a=10^3$, $L=1.2\times10^4$, then max tan $(\beta_t-\beta_r)=0.0144$ or max $(\beta_t-\beta_a)=50'$.

Thus for the assumed values (which are typical) the radial angle β_r deviates from the true direction of the dip β_t by less than one degree. On Fig. 6 computed values of $\beta_t-\beta_r$ are shown and for comparison Eq. 9 is plotted.

The approximate solution of the magnitude of the dip is obtained

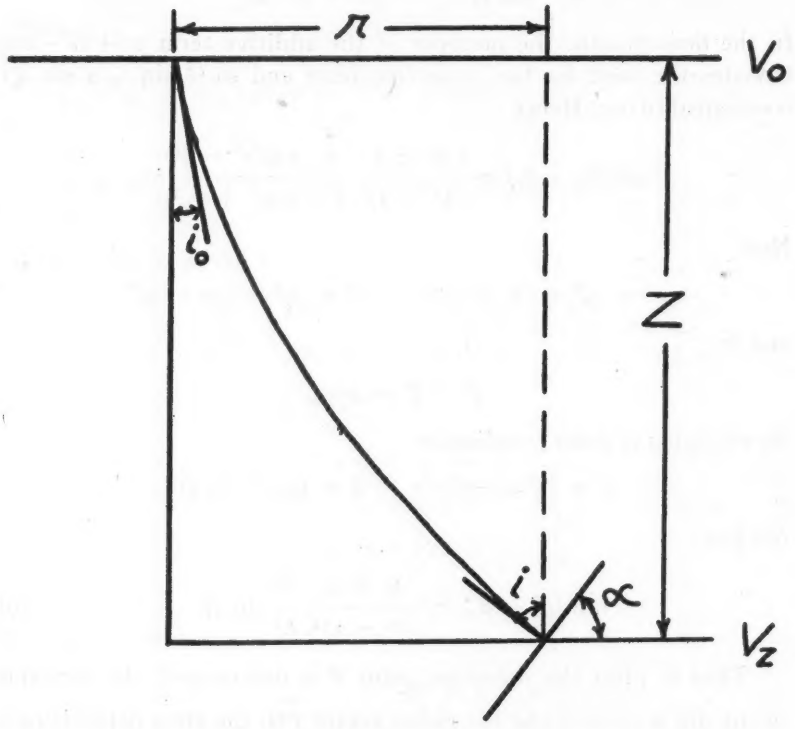


FIG. 4. Trajectory of normal incidence reflection.

by assuming that the dip is such that it would give normal incidence for a shot point at O (Fig. 3) and the reflection point R. Since the horizontal distances for this assumed reflection are known, the dip can be read immediately from a wave front chart. In this paper the dip values have been computed by means of Eq. 10 which is developed as follows.

Fig. 4 shows the trajectory whose horizontal and vertical com-

ponents are r and Z respectively. Since the normal to the trajectory at depth Z is supposed to have the same dip as the reflecting horizon, one has by virtue of Eqs. 4

$$\tan \alpha_r = \tan i = \frac{2\lambda\left(\frac{r}{L}\right)}{2\lambda^2 - 2A(r)}$$

or, since

$$2A(r) = \left(\frac{r}{L}\right)^2 + \lambda^2 + 1$$

$$\alpha_r = \tan^{-1}\left\{\frac{2\lambda\left(\frac{r}{L}\right)}{\lambda^2 - 1 - \left(\frac{r}{L}\right)^2}\right\}. \qquad (10)$$

Fig. 7 shows that $\alpha_t - \alpha_r$ is very small.

C. APPROXIMATE DETERMINATION OF THE DIRECTION OF DIP

It is often suggested that an oblique reflection can be corrected to a normal shot referred to the origin, O, of Fig. 3 by vectorially subtracting the normal Δt, $\Delta t_N^{(i)}$, from the observed Δt. As stated above the analytic treatment will be based on the use of $\Delta t_N^{(1)}$ but the numerical computations will be carried out for both $\Delta t_N^{(1)}$ and $\Delta t_N^{(2)}$.

In Fig. 5 the following are known quantities

$$\vec{b} = \text{observed } \Delta t = \vec{OF}$$

$$\vec{\Delta} = \text{normal } \Delta t = \vec{FG}$$

$$\phi = \text{angle } OFH.$$

It will be supposed that the directed line segment $\vec{OG}$ is the direction of the dip. Comparison is made between the angle OGH, which is β_a as defined above, and the quantities β_r and β_t. From Fig. 5 one has

$$\tan \beta_a = \frac{OH}{GH} = \frac{OH}{FH - FG} = \frac{b \sin \phi}{b \cos \phi - \Delta} = \frac{\sin \phi}{\cos \phi - \Delta/b}.$$

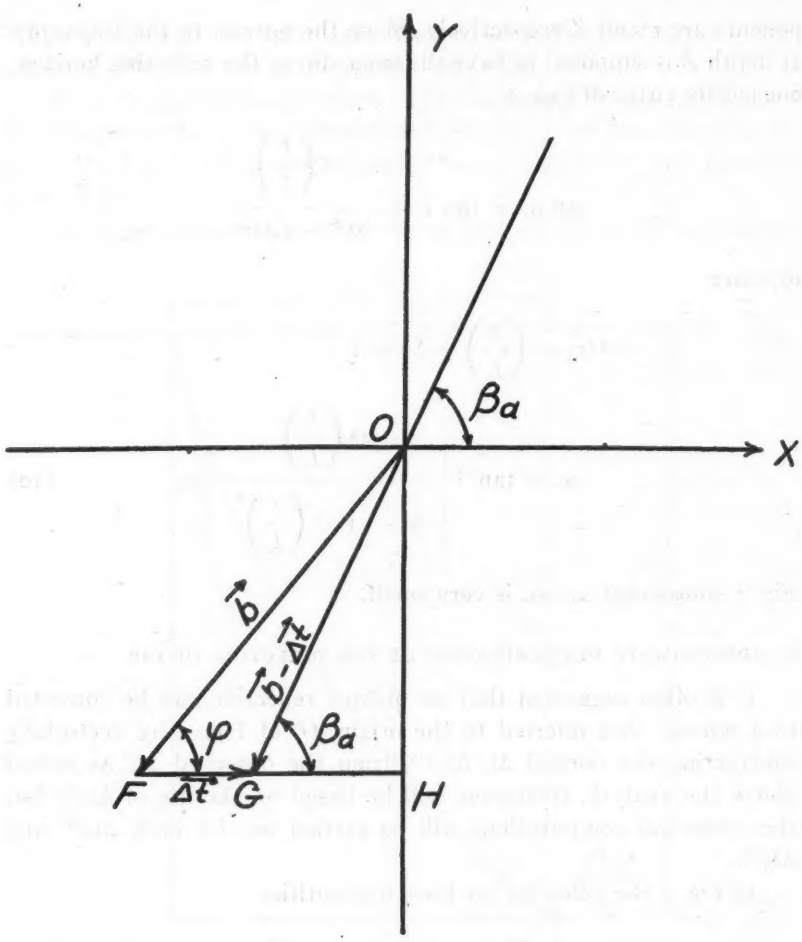


FIG. 5. Determination of approximate direction of dip by vector addition.

Let i_{ON} = angle with the vertical of the normal travel-path (defined above) at the surface

i_N = angle with the vertical of the normal travel-path at the depth Z

then

$$\frac{\Delta}{b} = \frac{\sin i_{ON}}{\sin i_{O_1}} = \frac{\sin i_N}{\sin i_1}.$$

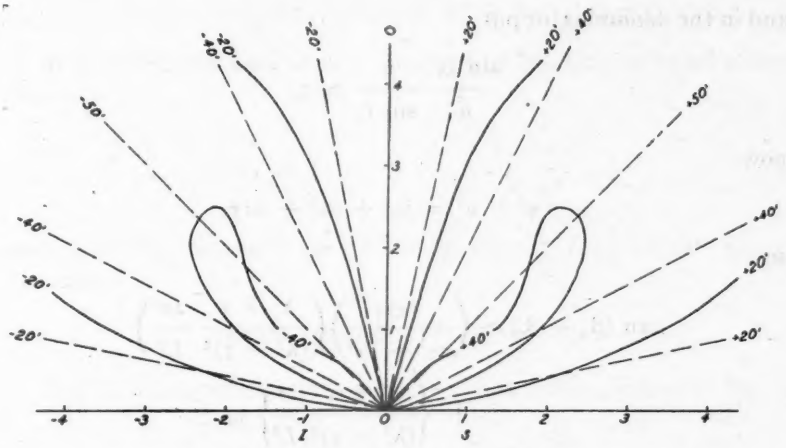


FIG. 6. Contours of $\beta_t - \beta_r$. Dashed curves are theoretical values from Eq. 9. Solid curves are from numerical examples. Scale values are thousands of feet.

It will be noted that although the given angle ϕ is expressed in terms of the coordinates of the reflection point P, we are not assuming that the coordinates of the point P are known. We are merely expressing the given quantities in terms that can be compared with the preceding expressions. From Fig. 3 it is seen that

$$\sin \phi = \frac{y_0}{\eta}; \qquad \cos \phi = \frac{x_0 + a}{\eta}$$

and hence

$$\tan \beta_a = \frac{y_0}{(x_0 + a) - a(\eta \sin i_N / a \sin i_\eta)}$$

$$\tan (\beta_a - \beta_r) = \frac{\tan \beta_a - \tan \beta_r}{1 + \tan \beta_a \tan \beta_r}$$

$$= a y_0 \frac{(\eta \sin i_N / a \sin i_\eta) - 1}{(y_0^2 + x_0^2 + a x_0) - a x_0 (\eta \sin i_N / a \sin i_\eta)}$$

"a" is the distance corresponding to the angle i_N, so as before in the numerator we set

$$\left\{ \frac{\sin i_N}{a} \frac{\eta}{\sin i_\eta} \right\} - 1 \simeq \frac{\lambda^2 + 1}{(\lambda^2 - 1)^2} \frac{1}{L^2} (\eta^2 - a^2)$$

and in the denominator put

$$\frac{\sin i_N}{a} \cdot \frac{\eta}{\sin i_\eta} \simeq 1$$

now

$$\eta^2 - a^2 = y_0^2 + x_0^2 + 2ax_0$$

so

$$\tan(\beta_a - \beta_r) \simeq \left(\frac{x_0 y_0}{x_0^2 + y_0^2}\right)\left(\frac{\lambda^2 + 1}{(\lambda^2 - 1)^2}\,\frac{2a^2}{L^2}\right) + \left\{\frac{\lambda^2 + 1}{(\lambda^2 - 1)^2}\,\frac{a}{L^2}\right\} y_0$$

or in polar coordinates

$$\tan(\beta_a - \beta_r) \simeq \frac{\lambda^2 + 1}{(\lambda^2 - 1)^2}\,\frac{a^2}{L^2}\sin 2\theta + \frac{\lambda^2 + 1}{(\lambda^2 - 1)^2}\,\frac{a}{L^2}\, r \sin\theta. \qquad (11)$$

A useful trigonometric identity is

$$\sin(\epsilon - \gamma) = \cos\epsilon \cos\gamma(\tan\epsilon - \tan\gamma)$$

Set

$$\epsilon = \beta_a - \beta_r; \qquad \gamma = \beta_t - \beta_r$$

and get

$$\sin(\beta_a - \beta_t) = \cos(\beta_a - \beta_r)\cos(\beta_t - \beta_r) \times \{\tan(\beta_a - \beta_r) - \tan(\beta_t - \beta_r)\}.$$

By virtue of Eqs. 9 and 11 this becomes

$$\sin(\beta_a - \beta_t) \simeq \cos(\beta_a - \beta_r)\cos(\beta_t - \beta_r)\left\{\frac{\lambda^2 + 1}{(\lambda^2 - 1)^2}\,\frac{a}{L^2}\right\} y_0$$

We have seen that $|\beta_t - \beta_r| < \pi/2$, actually less than a few degrees. So

$$0 < \cos(\beta_t - \beta_r) \leqq 1.$$

It is obvious from physical considerations that the angle $(\beta_a - \beta_r)$ remains $|\beta_a - \beta_r| < \pi/2$ and

$$0 < \cos(\beta_a - \beta_r) \leqq 1.$$

That is, both cosines are always positive and less than or equal to one. One has

$$0 < \sin(\beta_a - \beta_t) \leqq \frac{\lambda^2 + 1}{(\lambda^2 - 1)^2} \frac{a}{L^2} |y_0|. \tag{12}$$

As a numerical example take $\lambda^2 = 2.25$, $a = 10^3$, $L = 1.2 \times 10^4$. Eq. 12 becomes

$$\sin(\beta_a - \beta_t) \leqq 1.81 \times 10^{-5} y_0.$$

In Fig. 8 computed values of $\beta_a^{(1)} - \beta_t$ are shown. Values of Eq. 12

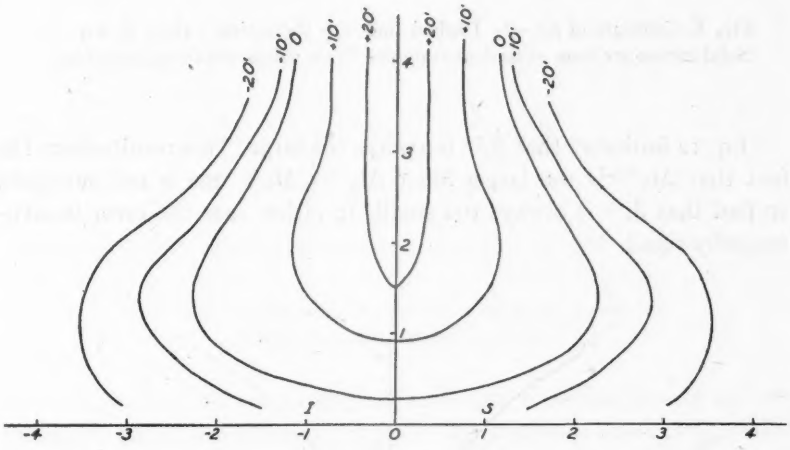


FIG. 7. Contours of $\alpha_t - \alpha_r$ based on numerical examples. Scale values are thousands of feet.

are superimposed. The lack of agreement in the two sets of curves probably results from setting the cosine terms equal to one.

The values of β_a are determined by the equation

$$\beta_a = \tan^{-1}\left\{\frac{\sin\phi}{\cos\phi - \Delta/b}\right\}$$

$\beta_a^{(1)}$ or $\beta_a^{(2)}$ results according as $\Delta t_N^{(1)}$ or $\Delta t_N^{(2)}$ is used for Δ. $\beta_a^{(2)} - \beta_t$ is shown on Fig. 9.

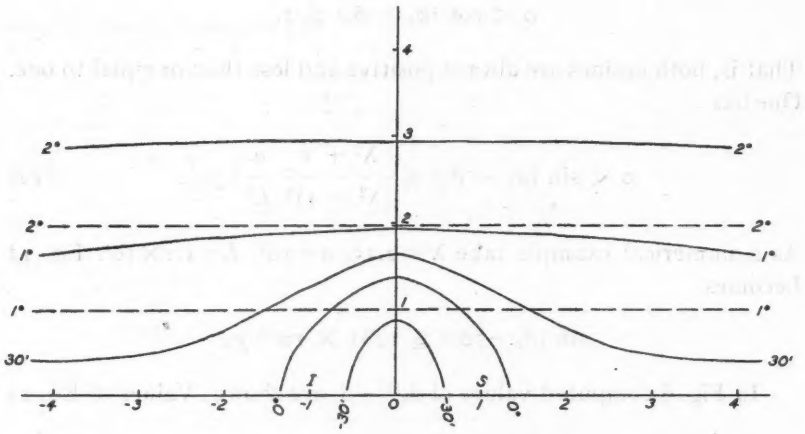


FIG. 8. Contours of $\beta_a{}^1-\beta_t$. Dashed lines are theoretical values of Eq. 12. Solid curves are from numerical examples. Scale values are thousands of feet.

Eq. 12 indicates that $\beta_a{}^{(1)}$ is always too large. This results from the fact that $\Delta t_N{}^{(1)}$ is too large. Since $\Delta t_N{}^{(2)} < \Delta t_N{}^{(1)}$ one is not surprised to find that $\beta_a{}^{(2)}$ is always too small. In either case the error is satisfactorily small.

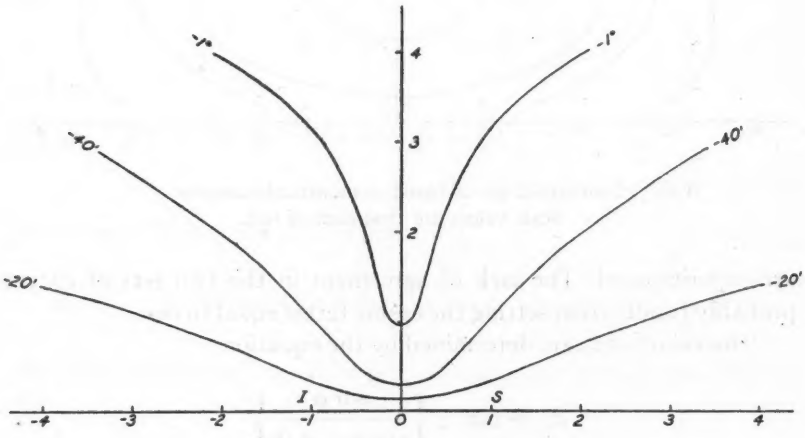


FIG. 9. Contours of $\beta_a{}^2-\beta_t$ based on numerical values. Scale values are thousands of feet.

D. REDUCTION TO THE NORMAL INCIDENCE PROBLEM

If one assumes that the vector $\vec{b}-\vec{\Delta t}_N^{(2)}$ is the correct $\vec{\Delta t}$ to be associated with the point O of Fig. 5, that $\beta_a^{(2)}$ is the direction of the dip, and that we may treat the data as though pertaining to a normal incidence reflection, then the location of the reflection point and the determination of the magnitude of the dip may be read from a wave

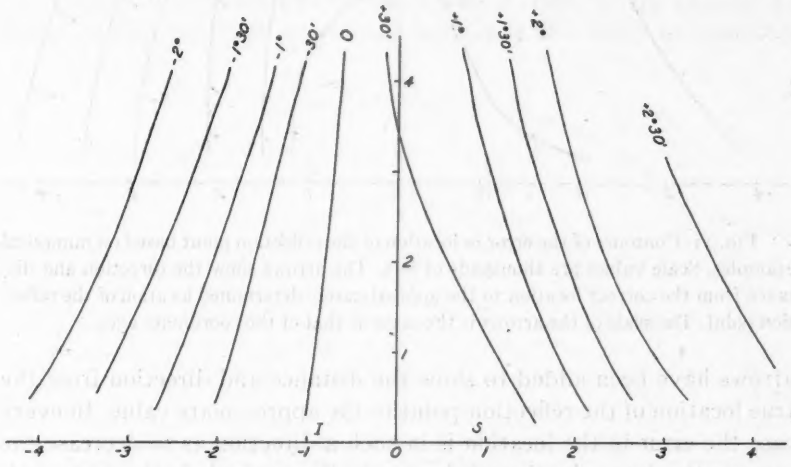


FIG. 10. Contours of $\alpha_i-\alpha_a^2$ based on numerical examples. Scale values are thousands of feet.

front chart. For the corresponding reflection time one should use the observed reflection time, T_r, minus the step-out time that would correct the normal travel-path to a vertical travel-path.

No analytic justification is made for all of the steps in this process but Fig. 9 (error in direction of the dip), Fig. 10 (error in magnitude of the dip), Fig. 11 (error in surface location of the reflection-point), and Fig. 12 (error in depth to the reflection-point) show the approximation to be highly satisfactory. The quantity contoured in Fig. 11 is the horizontal component of the distance from the true location of the reflection-point to the location obtained by the approximation. Fig. 12 shows the approximate value of the depth to the reflection point minus the true depth.

Actually the errors in the values of the depth and the location of the reflection-point are less serious than they may seem. On Fig. 11

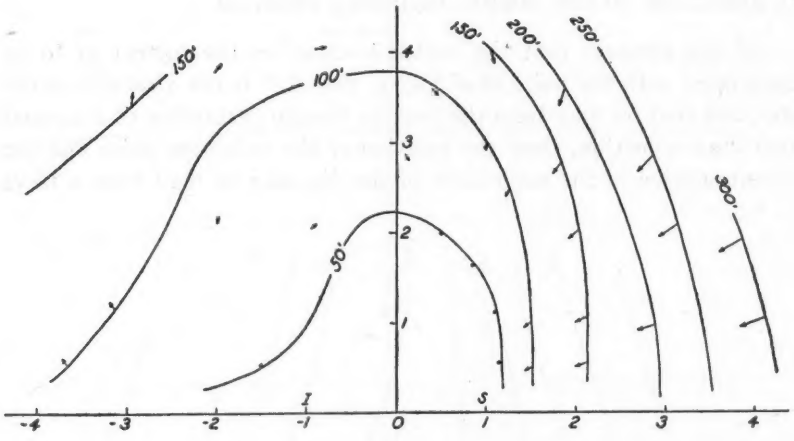


FIG. 11. Contours of the error in location of the reflection point based on numerical examples. Scale values are thousands of feet. The arrows show the direction and distance from the correct location to the approximately determined location of the reflection point. The scale of the arrows is the same as that of the coordinate axes.

arrows have been added to show the distance and direction from the true location of the reflection-point to the approximate value. In every case the error in the location is in such a direction as to decrease the error in the determination of the depth. For example in the first quad-

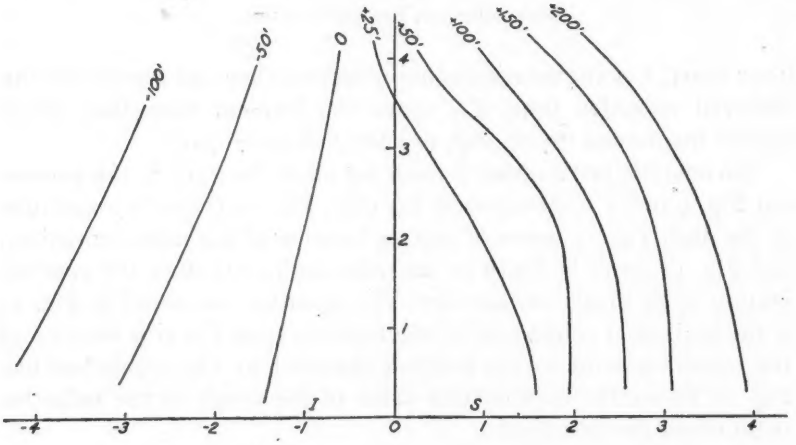


FIG. 12. Contours of the error in determining the depth of the reflection point based on numerical examples. Scale values are thousands of feet.

rant where the approximate depths are too large, the approximate location of the reflection-point is down dip where the depth is actually larger. It would perhaps have been better to have plotted in Fig. 12 the approximate depth minus the true depth evaluated at the approximate location of the reflection-point.

It is probable that the conversion of the oblique incidence problem to one of normal incidence is the approximate solution that is used most often. The numerical computations of Figs. 9, 10, 11, and 12 based on fifty reflection-points on a half plane at a depth of 6,000 feet

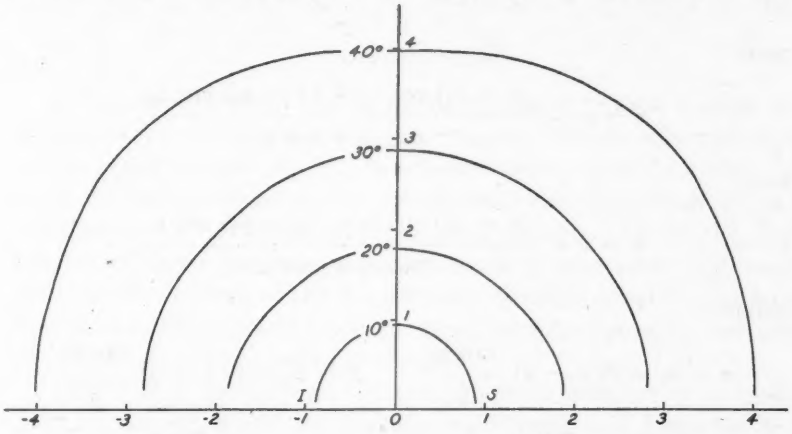


FIG. 13. Contours of the true dip, α_t, Scale values are thousands of feet.

show that it is good. It is possible that the increased danger of computational errors in the lengthy rigorous solution is sufficient to overweigh the small increase in accuracy.

In Fig. 13 the true dip, α_t, is contoured. These curves show the magnitude of dip required to give a reflection at any point 6,000 feet deep for a shot-point to instrument-spread distance of 2,000 feet and a velocity distribution given by

$$V = 5{,}400\left\{1 + \frac{Z \text{ feet}}{12{,}000}\right\} \text{ feet/sec.}$$

By means of these curves the dependence on the magnitude of dip of the errors of the various approximations may be observed. The dip of 20° corresponds to 1,900 feet per mile which is as large as is normally encountered. Each of the approximations has yielded very nominal errors for dips less than 20°.

The author is indebted to Shell Oil Company, Incorporated, for permission to publish the analysis presented in this paper.

APPENDIX

An analytic expression for tan β_t has been developed. To complete the formulae the corresponding development for tan α_t is given. From Eq. 2

$$\tan \alpha_t = \frac{\overline{PN}}{Z} = \frac{\sqrt{(x-u)^2 + (y-v)^2}}{Z}$$

now

$$x - u = \frac{(x - x_1)\cos i_\xi + (x - x_2)\cos i_\eta}{\cos i_\xi + \cos i_\eta}$$

and

$$y - v = \frac{(y - y_1)\cos i_\xi + (y - y_2)\cos i_\eta}{\cos i_\xi + \cos i_\eta}$$

where

$$x - x_1 = Z(x - a)\frac{\tan i_\xi}{\xi}; \qquad x - x_2 = Z(x + a)\frac{\tan i_\eta}{\eta}$$

$$y - y_1 = yZ\frac{\tan i_\xi}{\xi}; \qquad y - y_2 = yZ\frac{\tan i_\eta}{\eta}$$

so

$$(x - u) = \frac{Z(x - a)\dfrac{\sin i_\xi}{\xi} + Z(x + a)\dfrac{\sin i_\eta}{\eta}}{\cos i_\xi + \cos i_\eta}$$

$$(y - v) = \frac{\dfrac{\sin i_\xi}{\xi} + \dfrac{\sin i_\eta}{\eta}}{\cos i_\xi + \sin i_\eta} \cdot yZ$$

and finally

$$\tan \alpha_t = \frac{\left[\left\{(x-a)\dfrac{\sin i_\xi}{\xi} + (x+a)\dfrac{\sin i_\eta}{\eta}\right\}^2 + y^2\left\{\dfrac{\sin i_\xi}{\xi} + \dfrac{\sin i_\eta}{\eta}\right\}^2\right]^{1/2}}{\cos i_\xi + \cos i_\eta}$$

THE COMPUTATION OF OUTPUT DISTURBANCES FROM AMPLIFIERS FOR TRUE WAVELET INPUTS*

NORMAN RICKER†

ABSTRACT

A procedure for the computation of *amplifier output forms* for a true *wavelet* input form is outlined, and examples are given showing the manner in which these output forms may be determined from the known amplitude *vs.* frequency and phase *vs.* frequency characteristic curves of the amplifiers.

INTRODUCTION

It has been brought out in previous papers[1,2,3] that a sharp explosion at a point in the earth gives rise to a seismic disturbance of a characteristic, definite, and determinable form, dependent upon the nature of the *absorption spectrum* of the earth, and that a seismogram is composed of a succession of overlapping *wavelets*. Due to the large number of these wavelets, the seismogram is necessarily very complicated. Since some of the wavelets are of much greater amplitude than others, and so stand out above the general background, they may be picked for travel time determinations.

Now it is of primary importance in seismic prospecting to insure that the amplifier and its auxiliary equipment, the geophone and galvanometer, do not add to the complexity of the seismogram by badly distorting the wavelets they are required to pass. We can build a good distortionless system for a faithful recording of these seismic wavelets by providing a geophone of low natural frequency (around one cycle per second), an amplifier having a flat response characteristic from, say, one cycle per second to one thousand cycles per second, and with a linear phase shift characteristic, and a galvanometer having a high natural frequency (around 500 cycles per second) and seven-tenths critically damped. This high quality system is quite satisfactory for fundamental research studies in which it is desired to make a critical study of the earth motions. However, in practical seismic prospecting there are numerous other matters, such as ground

* Presented at the annual meeting, Dallas, Texas, March 21, 1944.

† The Carter Oil Co., Tulsa, Okla.

[1] GEOPHYSICS, Vol. 5, No. 4 (Oct. 1940), pp. 348–366.

[2] GEOPHYSICS, Vol. 6, No. 3 (July 1941), pp. 254–258.

[3] Bull. Seis. Soc. Amer. Vol. 33, No. 3 (July 1943), pp. 197–228.

roll suppression and ruggedness of geophone construction, which generally make it desirable to deviate from this distortionless system. When the overall amplitude and phase characteristics of the system depart from those of a distortionless system, there will be a distortion of the wavelet form in passing through the apparatus. We must take care that this distortion is kept within reasonable limits. It is necessary, therefore, to know the form of the amplifier's output disturbance when a true wavelet form is passed into it. In order to determine this output form, we have followed two lines of procedure.

1. THE EXPERIMENTAL APPROACH

One line of procedure is the experimental approach. In this procedure we have constructed a photo-electric *wavelet generator* in which a stencil, cut in the form of the symmetrical, velocity-type seismic wavelet, is carried by a rotating drum and is allowed to sweep over a slit controlling the light to a photo-electric cell. The amplified output of the photocell gives a current which follows very well the form of the velocity-type wavelet as it is observed at a distance from the shot. The output from the wavelet generator is then passed through the amplifier and galvanometer and an oscillogram is made. The amplifier output form and the true wavelet input form are carried on separate traces on the oscillogram and so can be compared with respect both to wavelet shape and time delay.[4] This experimental procedure, of course, requires that the amplifier first be built before its output form may be determined.

2. THE ANALYTICAL APPROACH

The other line of procedure is by direct computation. This procedure offers the advantage that the output forms may be computed for any amplitude and phase characteristics which are consistent with sound principles of design and so a continuous program of design and evaluation can be carried along, and only those amplifiers built which give a satisfactory calculated output form.

THE VELOCITY-TYPE SEISMIC WAVELET

Since it is the velocity-type seismic wavelet which passes through the amplifier and appears on the seismogram of the electrical seismo-

[4] Overall studies of geophone, amplifier, and galvanometer, also are made by placing the geophone on a shaking table and driving the shaking table so that its motion follows the displacement-type seismic wavelet.

graph, it is appropriate at this point to describe this wavelet in some detail. This wavelet form, shown in Fig. 1, is represented by the symbol:

$$\mathcal{V}(u \mid R)$$

wherein

$$u = \left(\frac{2\omega_0}{t_0}\right)^{1/2} (t - t_0)$$

ω_0 being a constant of the medium, t the time, and t_0 the travel time of

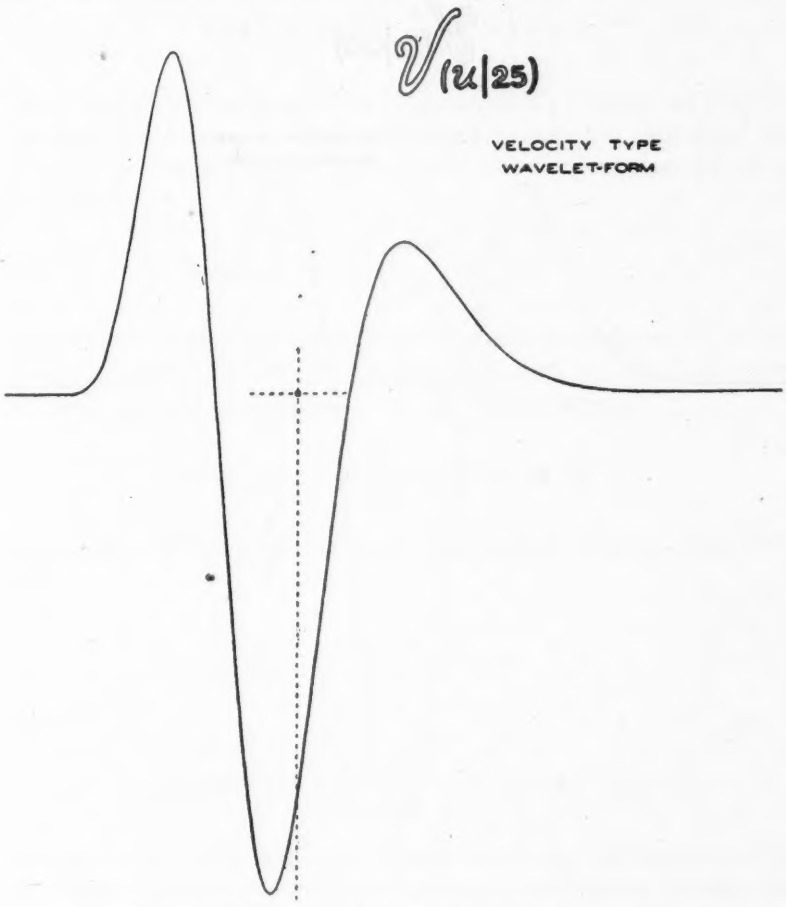


FIG. 1. Velocity type wavelet-form near the shot point.

the wavelet center. The parameter R is called the numerical distance and is given by

$$R = \frac{\omega_0 r}{c}$$

r being the true radial distance and c the wavelet velocity in the medium. Since $r/c = t_0$, it follows that $R = \omega_0 t_0$, which is also the numerical time of the wavelet center.

At points near the shot, so that t_0 is small, this wavelet is distorted

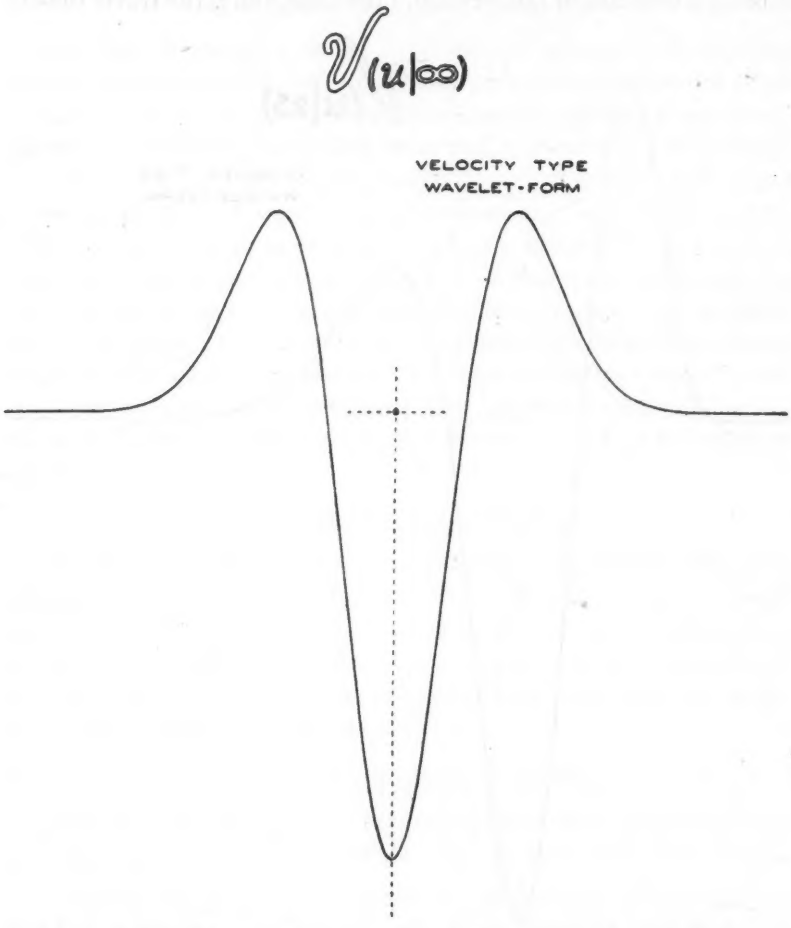


FIG. 2. Velocity type wavelet-form at larger distances from the shot point.

from the symmetrical form, and is as shown in Fig. 1, but as the distance from the shot is increased without limit, the wavelet form approaches the symmetrical form given in the earlier papers and shown in Fig. 2. Since it is only at points quite near the shot that a departure from the symmetrical form can be observed, it is quite satisfactory, generally, to use the symmetrical form in the amplifier computations. This symmetrical form is represented by the symbol

$$\mathfrak{V}(u \mid \infty)$$

and can be expressed analytically by

$$\mathfrak{V}(u \mid \infty) = \frac{\sqrt{\pi}}{2}\left(\frac{u^2}{4} - \frac{1}{2}\right)e^{-u^2/4}.$$

Since the point from which time is measured is arbitrary, we shall for the purpose of these computations agree to measure time from the center of the input wavelet. So the input wavelet form may be represented by

$$\mathfrak{V}(u \mid \infty) = \frac{\sqrt{\pi}}{2}\left(\frac{6t^2}{b^2} - \frac{1}{2}\right)e^{-6t^2/b^2}$$

wherein t is now the time measured from the wavelet center and b is the breadth of the wavelet in seconds between its two maxima. This wavelet form may also be represented by the infinite integral

$$\mathfrak{V}(u \mid \infty) = -\int_0^\infty \xi^2 e^{-\xi^2} \cos \xi u \cdot d\xi.$$

By a change of the variable of integration, and by defining a frequency f_1 by

$$f_1 = \frac{\sqrt{6}}{\pi} \cdot \frac{1}{b}$$

we have

$$\mathfrak{V}(u \mid \infty) = -\int_0^\infty \frac{f^2}{{f_1}^2} e^{-f^2/{f_1}^2} \cos 2\pi f t \cdot df/f_1$$

wherein $f = f_1 \cdot \xi$. This last integral form states that the wavelet is the sum of an infinite array of single frequency components covering the entire range of frequencies from zero to infinite frequency. Also, the

integral form states that all of these single frequency components are in phase at the wavelet center. This, of course, accounts for the deep valley at the center of the wavelet.

THE SPECTRUM OF A WAVELET

Now in this infinite array of single frequency components, there is a certain functional relation between the amplitude of a given component and its frequency. This function represents the *spectrum* of the wavelet, and is given by

$$\xi^2 e^{-\xi^2}$$

where

$$\xi = \frac{\pi}{\sqrt{6}} \cdot bf.$$

This spectral function is shown in Fig. 3.

It will be noticed that the component of maximum amplitude is of frequency $\sqrt{6}/\pi b$. Thus, if the wavelet breadth is 1/50 second (popularly referred to as a 50-cycle reflection) the component of maximum amplitude in the spectrum has a frequency of around 39 cycles per second.

THE COMPUTATION OF OUTPUT DISTURBANCES

Let us suppose that we have an amplifier system (which may include the galvanometer) into which we will pass a voltage following the form of the symmetrical velocity-type seismic wavelet. Let this amplifier system have an amplitude response characteristic given by $F(\xi)$ and a phase characteristic given by $\theta(\xi)$. If the input wavelet form is given by

$$\mathcal{V}(u \mid \infty) = -\int_0^\infty \xi^2 e^{-\xi^2} \cos \xi u \cdot d\xi$$

then the output form will be

$$W(u) = -\int_0^\infty \xi^2 e^{-\xi^2} F(\xi) \cos \left[\xi u - \Theta(\xi)\right] \cdot d\xi$$

which may be written

$$W(u) = M(u) + N(u)$$

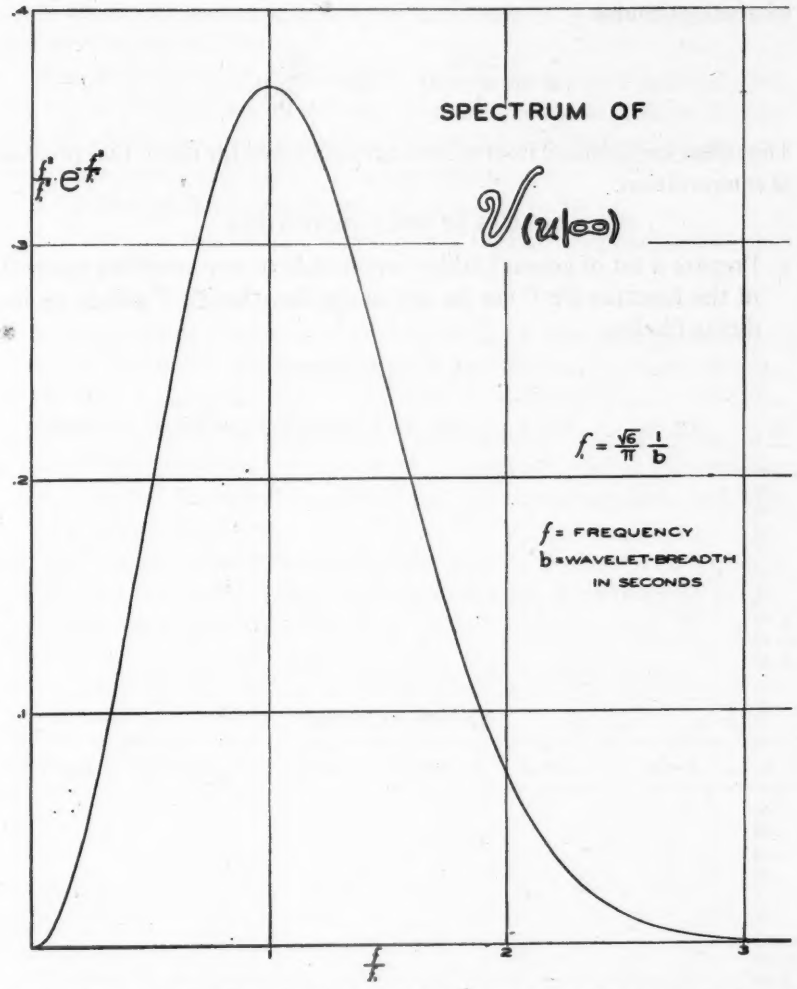


FIG. 3. Spectrum of the symmetrical (infinite distance) velocity type wavelet, as a function of f/f_1, in which f_1 is related to the breadth b of the wavelet by $f_1 = \sqrt{6}/\pi b$.

where

$$M(u) = -\int_0^\infty \xi^2 e^{-\xi^2} \cos \xi u \cdot F(\xi) \cos \Theta(\xi) \cdot d\xi$$

and

$$N(u) = -\int_0^\infty \xi^2 e^{-\xi^2} \sin \xi u \cdot F(\xi) \sin \Theta(\xi) \cdot d\xi$$

wherein, of course

$$u = \frac{2\sqrt{6}}{b} \cdot t; \qquad \xi = \frac{\pi b}{\sqrt{6}} \cdot f.$$

The following detailed instructions are suggested for the actual process of computation.

DETAILS OF THE COMPUTATION

1. Prepare a set of general tables (applicable to any amplifier system) of the function $\xi^2 e^{-\xi^2} \cos \xi u$ and of the function $\xi^2 e^{-\xi^2} \sin \xi u$ as indicated below

$\xi^2 e^{-\xi^2} \cos \xi u$ TABLE

ξ	$u=.0$	$u=.2$	$u=.4 \cdots u=11.6$	$u=11.8$	$u=12.0$
.00					
.02					
.04					
.06					
.					
.					
.					
3.16					
3.18					
3.20					

$\xi^2 e^{-\xi^2} \sin \xi u$ TABLE

ξ	$u=.2$	$u=.4$	$u=.6 \cdots u=11.6$	$u=11.8$	$u=12.0$
.00					
.02					
.04					
.06					
.					
.					
.					
3.16					
3.18					
3.20					

The limiting range of ξ is determined by the upper limit of important frequencies in the wavelet spectrum and depends upon the breadth, b, of the input wavelet. For a wavelet breadth of .02 second, which is a representative value, the limit 3.20 in ξ carries us out to a frequency of about 125 cycles per second which appears to be sufficient. The limiting range of u is determined by the magnitude of prolongation of the disturbance, due principally to the degree of phase shift given by the function $\theta(u)$. The value $u=12.0$, for input wavelet

of breadth .02 second corresponds to a time of ±.049 second from the wavelet center.

For preparation of these tables and the tables that are to follow, the tables prepared by the *Works Projects Administration for the City of New York* under the sponsorship of the *National Bureau of Standards* have been found most useful. The two volumes:

a. Tables of the Exponential Function MT2—1939

b. Tables of Sines and Cosines for Radian Arguments MT4—1940

are applicable to these computations.

2. Select an input wavelet breadth b seconds. (A representative value is $b=.02$ second). This enables ξ to be determined from the frequency.
3. From the characteristic curves of the amplifier system, wherein F and θ are given as functions of the frequency, replot as functions of ξ, with F expressed in an arithmetical amplitude scale and with θ expressed in radians.
4. From values taken from the graphs under (3) above and with the help of the general tables, prepare tables for the particular amplifier system as indicated below.

TABLE OF COSINE CURVES $\xi^2 e^{-\xi^2} \cos \xi u \cdot F(\xi) \cdot \cos \theta(\xi)$

ξ	$u=0$	$u=.2$	$u=.4 \cdots u=11.6$	$u=11.8$	$u=12.0$
.00					
.02					
.04					
.06					
.					
.					
.					
3.16					
3.18					
3.20					

TABLE OF SINE CURVES $\xi^2 e^{-\xi^2} \sin \xi u \cdot F(\xi) \cdot \sin \theta(\xi)$

ξ	$u=.2$	$u=.4$	$u=.6 \cdots u=11.6$	$u=11.8$	$u=12.0$
.02					
.04					
.06					
.					
.					
.					
3.16					
3.18					
3.20					

5. With these functions tabulated under (4) above, plot on separate sheets of graph paper (about 32″ by 20″)
   a. The family of cosine curves with u as a parameter.
   b. The family of sine curves, with u as a parameter.

Due to the large number of these curves, it is generally desirable to plot these from $u=0$ to $u=6$ on one graph and those from $u=6.2$ to $u=12.0$ on another one, with the curves for integral values of u colored in order to follow them.

6. Determine the areas under these curves of (5) above by means of polar planimeter and prepare the tables indicated below.

u	$M(u)$	$N(u)$	$W(u)=M(u)+N(u)$	$W(-u)=M(u)-N(u)$
0				
.2				
.4				
.6				
.				
.				
.				
11.6				
11.8				
12.0				

7. Plot $W(u)$ against the time, t, with the aid of

$$t = \frac{b}{2\sqrt{6}} \cdot u.$$

In Fig. 4 are shown cosine curves and in Fig. 5, sine curves described under (5) above, and in Figs. 6 and 7 are shown the forms of the output disturbances computed for two amplifier systems whose characteristic curves also are given. The curves of Figs. 4 and 5 are those used in computing the output form of Fig. 7.

After some experience a good computer can compute the ouput form of an amplifier in from two to three weeks provided the general tables are already at hand. In spite of the effort involved, it is often much more satisfactory to carry out these computations than to build an amplifier and get it into operation for the tests.

In comparing experimentally determined output forms with the computed forms, the agreement has been so close that no difference has been observable.

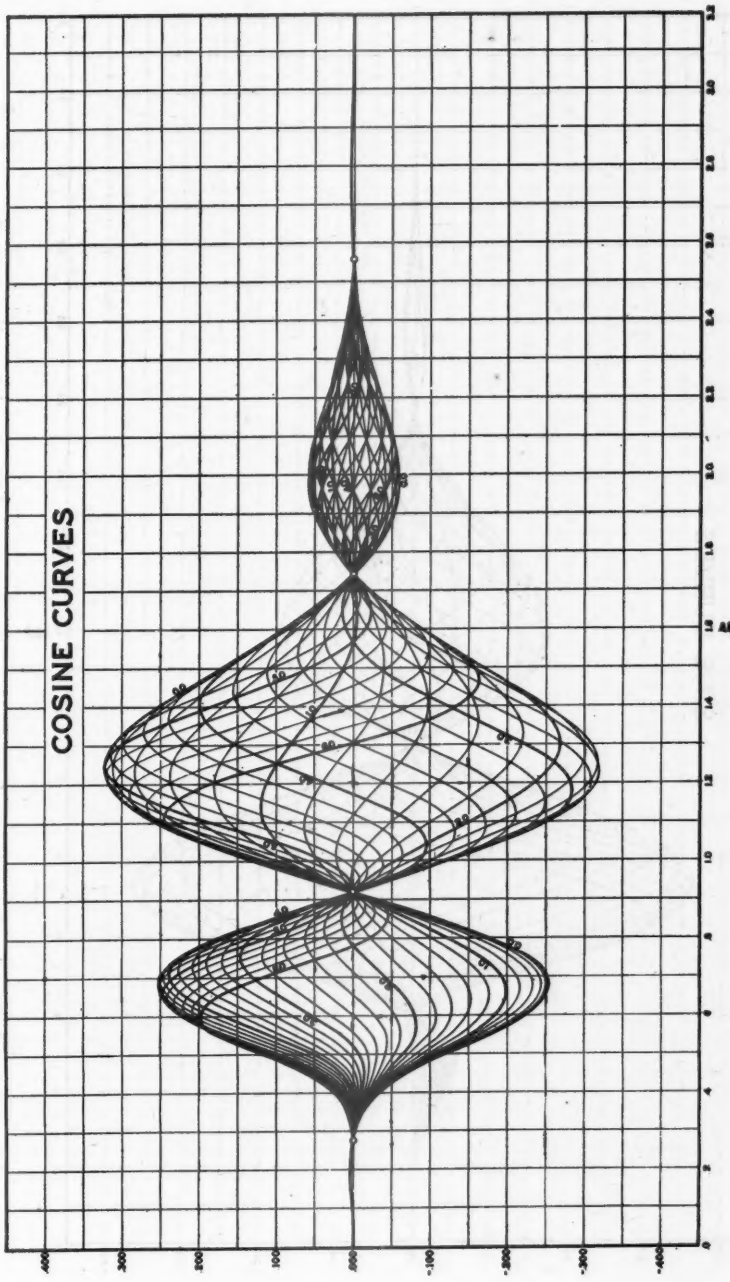


FIG. 4. The cosine curves for the amplifier response $F(\xi)$; $\theta(\xi)$ of Fig. 7 as a function of ξ and u.

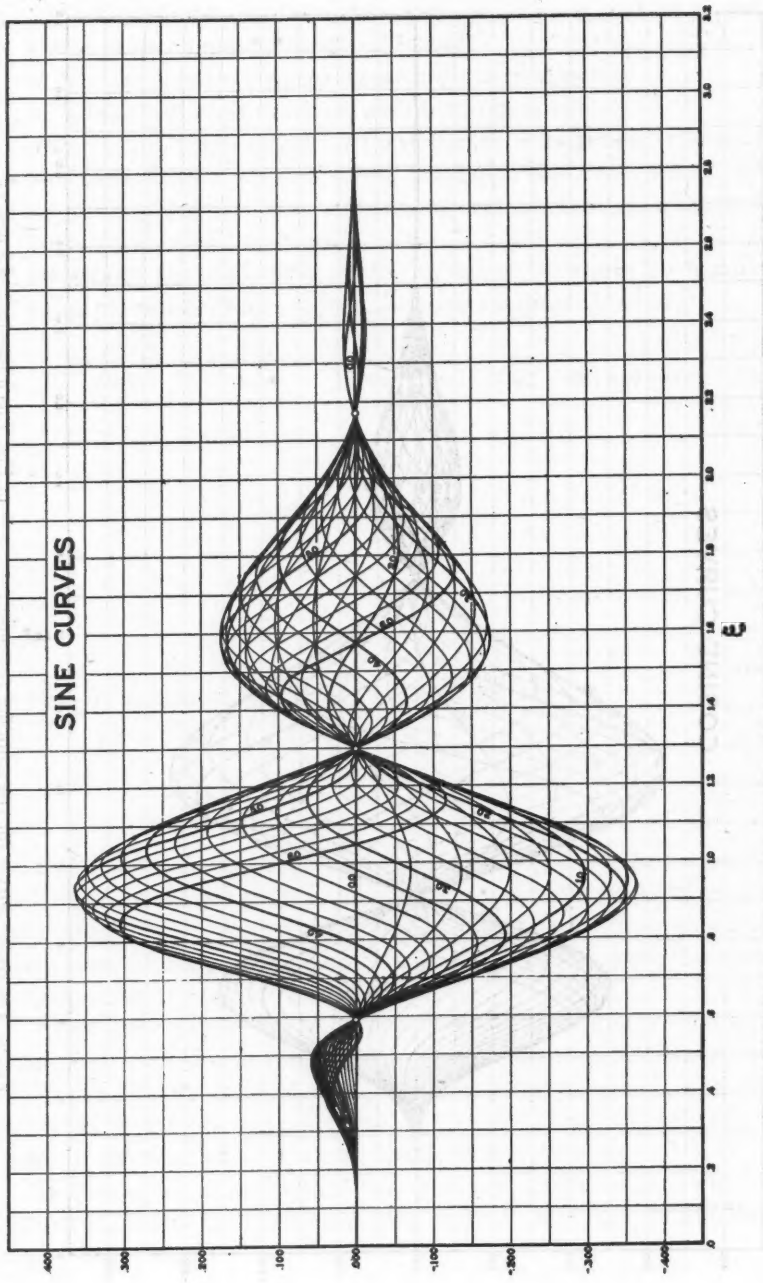


FIG. 5. The sine curves for the amplifier response $F(\xi)$; $\theta(\xi)$ of Fig. 7 as a function of ξ and u.

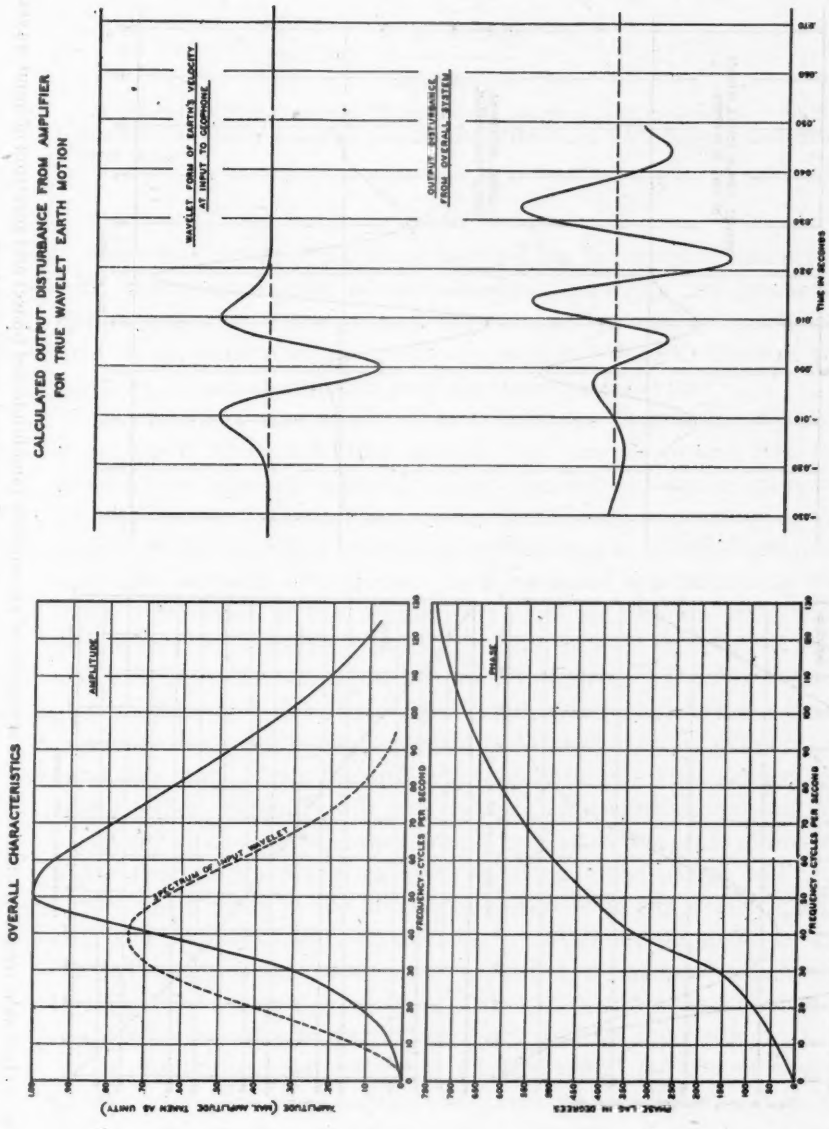


FIG. 6. Left side: overall transmission characteristics of an amplifier (amplitude and phase) and spectrum of input wavelet.
Right side: amplifier input wavelet, and calculated amplifier output.

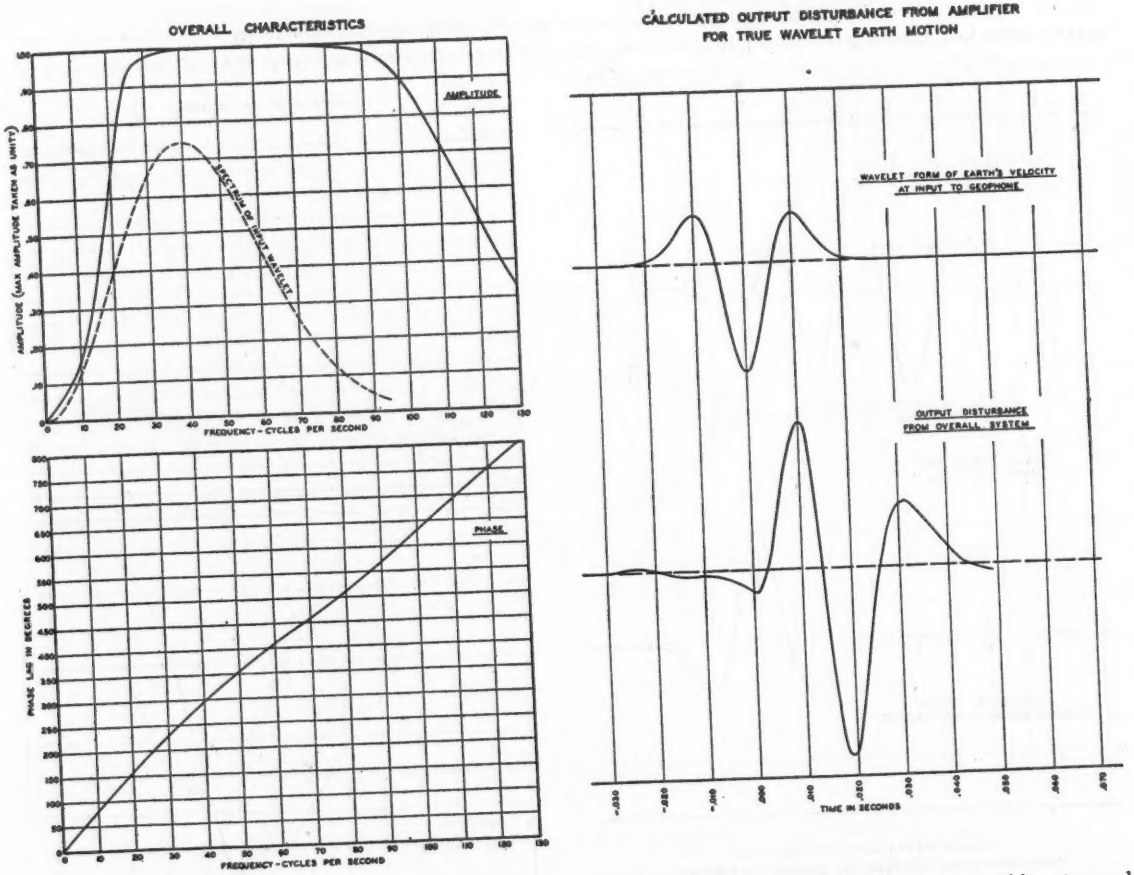


FIG. 7. Left side: overall transmission characteristics of an amplifier (amplitude and phase) and spectrum of input wavelet.
Right side: amplifier input wavelet, and calculated amplifier output.

THE PRINCIPLE OF VARIATION IN PATH WITH AN APPLICATION TO STRUCTURAL MAPPING*

H. M. EVJEN†

ABSTRACT

A general functional analysis of the low frequency electric exploration problem is presented. The theory is applied to some field data where a fair degree of subsurface control exists.

THEORY

An unusual type of mathematical problem has arisen in connection with the interpretation of measurements involving low frequency electric currents in the ground. Its solution has had an immediate field of application of the greatest practical value. Critique of the handling of this unorthodox problem therefore is invited.

The problem may be stated as follows: An electromagnetic field is set up in the conducting ground. The current passed into the ground may represent a steady state, sinusoidal or square wave, or may be transient. The gradient of the electric field is measured at the surface of the ground in specified directions and at specified locations and time intervals. The gradient thus measured is a function of the space coordinates. If the ground were perfectly uniform and homogeneous we would obtain a regular function with no singularities anywhere except at the surface of the ground where the assembly of energizing cables and electrodes are located, which, borrowing a term from radio technique, may be called the transmitter. If, on the other hand, the ground contains surfaces of discontinuity, the function will possess other singularities. It may be said that perturbation potentials are set up which behave as though they originated in a series of images of the transmitter. Mathematically speaking, these images will constitute singularities in the functional behaviour of the electric gradient. The problem here to be solved is to determine the depth to the center of origin of the predominant perturbation potential, which will be called "the center of symmetry." This is to be done with a minimum of assumptions concerning the electric properties of the medium.

By the proper arrangement of electrodes and the proper choice of time interval in which measurements are made, the direct effect of the transmitter may be practically eliminated. If this condition

* Manuscript received August 1, 1944.

† The Elflex Company, Houston, Texas.

Right side: amplifier input wavelet, and calculated amplifier output.

should not be fulfilled, the depth obtained from the evaluation of the observed data would be zero. A suitable arrangement will be described in conjunction with an application of the theory to be given.

The only assumption which will be made is that the medium shall have a vertical axis of symmetry. Although this will never be rigorously true, it will be frequently correct for all practical purposes.

For simplicity, measurements will be carried out only on the polar axis of the transmitter so that measurements are carried out also in the plane of the polar axis of any perturbation potential. Azimuthal components are thereby eliminated and nothing would be added by more generality in this respect.

A general solution for the electric vector is,

$$\boldsymbol{E} = \sigma^{-1} \operatorname{curl} \operatorname{curl} \boldsymbol{A}, \tag{1}$$

where the vector potential, $\boldsymbol{A}$, is a solution of the wave equation, and σ is the electric conductivity.

It may be verified that under the stated conditions, the solution has the following functional form:

$$E_x = f\left[\frac{z^2}{r^3}Q_1(w) - \frac{x^2}{r^3}Q_2(w)\right], \tag{2}$$

where f is the frequency, x is the distance along the polar axis from the center of the transmitter, z is the depth to the center of symmetry, and

$$r^2 = x^2 + z^2. \tag{3}$$

Q_1 and Q_2 are regular functions of the socalled numerical distance, w, defined by,

$$w = 2\pi r(f\sigma 10^{-9})^{1/2}, \tag{4}$$

which, in practical units, becomes

$$w = 1.1r(f\sigma)^{1/2}, \tag{5}$$

where r is now measured in units of 1000 feet, the frequency is in cycles per second, and the conductivity in reciprocal ohm-feet.

For a transient rather than a steady state, this general solution is only slightly modified, the frequency parameter being replaced by time.

For a non-sinusoidal steady state Eq. 2 remains substantially in force, f being the fundamental frequency.

The problem to be solved now is this: suppose E_x is known experimentally as a function of the two independent variables, x and f, to determine from Eq. 2 the value of the depth z.

The problem turns out to be quite simple. Before the solution is written out, however, note that the electric gradient E_x itself is never observed, but only a potential drop, P, which for practical purposes is proportional thereto. Aside from a proportionality factor which does not concern us, E_x therefore may be replaced by P in Eq. 2.

Now consider the quantities defined by the partial derivatives of P in the following equations:

$$U = \frac{\partial}{\partial x}\left(\frac{1}{x}\frac{\partial P}{\partial x}\right), \tag{6}$$

$$V = 10\frac{\partial P}{\partial x} - 4f\frac{\partial^2 P}{\partial f \partial x}, \tag{7}$$

$$W = x\left[15P - 12f\frac{\partial P}{\partial f} + 4f^2\frac{\partial^2 P}{\partial f^2}\right]. \tag{8}$$

From these functions we can form,

$$r^2 = [-V \pm (V^2 - 4UW)^{1/2}]/2U, \tag{9}$$

a relation which is satisfied identically by Eq. 2.

Eq. 9, therefore, is the desired solution.

It remains to compute from the observed values of P, for different values of x and f, the five independent partial derivatives appearing in Eqs. 6, 7, and 8. This problem is best tackled by the method of least squares.

We shall not go into the details except to say that a method developed by E. Condon[1] some fifteen years ago, and utilizing orthogonal functions, is admirably fitted for this work and is far superior to conventional least square methods. The final outcome of the calculations, of course, is the same, but Condon's method is much more straightforward and less subject to computational errors.

The procedure is to present the function $P(x, f)$ as a Taylor expansion around a convenient pair of volues x_0, f_0. That is,

[1] E. Condon: *The rapid fitting of a certain class of empirical formulas by the method of least squares*. University of California Press (1929).

$$P(x, f) = P(x_0, f_0) + (x - x_0)\frac{\partial P}{\partial x} + \frac{(x - x_0)^2}{2!}\frac{\partial^2 P}{\partial x^2} + \cdots$$
$$+ (f - f_0)\frac{\partial P}{\partial f} + \frac{(f - f_0)^2}{2!}\frac{\partial^2 P}{\partial f^2} + \cdots \qquad (10)$$
$$+ (x - x_0)(f - f_0)\frac{\partial^2 P}{\partial x \partial f} + \cdots$$

in which it is understood that the values of the derivatives are taken at x_0, f_0.

If P now is represented, by the method of least squares, by the first few terms in this power series, it follows that the computed coefficients in this series give directly the desired partial derivatives.

The quantities U, V, and W are obtained from a linear combination of said coefficients.

It will be noticed that the quantities U, V, and W are independent of the units in which f is measured. Also, Eq. 9 yields r in terms of the same units in which x is measured. Therefore the most convenient units may be arbitrarily picked.

As an illustration, let P be given for the following values of the independent variables, and let the subscripts i and j denote these values:

$$i = -1, 0, 1 \qquad j = -1, 0, 1$$
$$x = 3, 4, 5 \qquad f = 1, 2, 3.$$

Also, transform Eq. 9 slightly to read as follows:

$$r^2 = x_0^2(-\beta + (\beta^2 - \alpha\gamma/2)^{1/2})/\alpha. \qquad (11)$$

The quantities α, β, and γ are related to U, V, and W in a manner which may be easily derived by comparing Eqs. 10 and 11. They are dimensionless and are introduced merely for the convenience of computation. They have the advantage that least square analysis in terms of them yields a simple rule, similar to the well known Simpson's Rule, in which only small integral numbers occur. The rule may be stated as follows:

$$\alpha = \sum_i \sum_j \alpha_{ij} P_{ij}$$
$$\beta = \sum_i \sum_j \beta_{ij} P_{ij} \qquad (12)$$
$$\gamma = \sum_i \sum_j \gamma_{ij} P_{ij}$$

where the coefficients α_{ij}, β_{ij} and γ_{ij} are presented in the following table:

TABLE I. COEFFICIENTS FOR $x_0=4$, $f_0=2$

i	j	α_{ij}	β_{ij}	γ_{ij}
−1	−1	9	−11	23
−1	0	9	−5	−22
−1	1	9	1	−1
0	−1	−16	0	38
0	0	−16	0	−7
0	1	−16	0	14
1	−1	7	11	23
1	0	7	5	−22
1	1	7	−1	−1

APPLICATION OF THEORY TO FIELD RESULTS

The theory here propounded has a useful field of application in mapping relatively shallow "electric structure." Such mapping is particularly useful in many faulted areas where existing methods may have difficulty in mapping structure accurately. The utility of the method presupposes an electric key horizon which has predominant effect upon the measurements.

As an electric well log will disclose, the ground has a multitude of electric surfaces of discontinuity. Each such interface gives rise to a singularity in the electromagnetic field which is reflected in the functional behavior of the potential drop measured at the surface of the ground. The analysis described above gives the depth to the center of symmetry of the aggregate of all these effects. In order that the depths thus computed shall be correlatable with the depths to a definite horizon, this horizon must have a predominant effect on the measured results.

Such predominance depends on the electric contrast of the horizon, its depth and thickness, etc., but also on the chosen values of the parameters x_0 and f_0 and upon the measuring arrangement in general. Thus, for the conventional type of AC resistivity measurement in which frequencies as high as 50 cycles per second were used, which heavily attenuated deeper effects, and, moreover, the component of the surface potential in phase with the energizing current was measured, the predominant effect was the primary effect from the singularity at the surface of the ground, *i.e.*, the energizing electrodes. Hence, for the conventional type of measurements, the depth of the center of symmetry was zero.

In the field experiments here to be described frequencies of the order of one cycle per second were used. Moreover, a special commutator was used in which the current was intermittently interrupted and potential measurements were made, at the surface of the ground, during current gaps while no current was flowing through the electrodes into the ground.[2] This measuring arrangement practically eliminates the primary effect and makes some deeper horizon predominant in its effect upon the measured potential.

The transmitter was a pair of grounded electrodes through which a cyclically reversed current of about 1.3 amperes was passed. These current electrodes were 1500 feet apart. The "receiver" consisted of two grounded electrodes also spaced 1500 feet apart and collinear with the current electrodes.

The potential was picked up during current gaps, as already described, and was balanced against a measuring potential proportional, in virtue of a network connection with the current circuit, to the energizing current.

Observations were made at the frequencies 0.5, 1.0, and 1.5 cycles per second. Since the computed quantities are independent of the frequency units, these values have been denoted for convenience by 1, 2, and 3.

Observations were made for separations of 2250 feet, 3000 feet, and 3750 feet between the center of the receiver and the center of the transmitter, the midpoint of the electrode configuration remaining fixed. With $x_0 = 3000'$ in Eq. 11, the values of the other independent variables therefore are 3, 4, and 5 as called for in the illustration of the theory given above.

The observed potentials in microvolts per ampere are given in the following table:

TABLE II. OBSERVED POTENTIAL DROPS

x	f	Sta. 10	Sta. 10½
2250′	0.5	−5.4	−3.8
2250′	1.0	−5.7	−4.7
2250′	1.5	−6.3	−5.7
3000′	0.5	−1.8	−1.7
3000′	1.0	−2.5	−1.8
3000′	1.5	−2.9	−2.4
3750′	0.5	−1.2	−0.9
3750′	1.0	−1.4	−0.9
3750′	1.5	−1.5	−1.4

[2] See W. B. Lewis. *Working depths for low frequency electrical prospecting,* GEOPHYSICS, Vol. X, No. 1 (Jan. 1945); particularly Fig. 1, p. 64.

The depths to the center of symmetry at the two stations here tabulated are given by Eq. 11 after least square determination of α, β, γ as 1880 feet and 1330 feet, respectively. If the effects giving rise to these potentials can be associated primarily with a single interface, the depth to this interface should be one-half the depth to the center of symmetry or 940′ and 665′ respectively.

The location of this test is southwest of the Darst Creek field in Guadalupe County, Texas, in the socalled Nigger Hill Area. A hole,

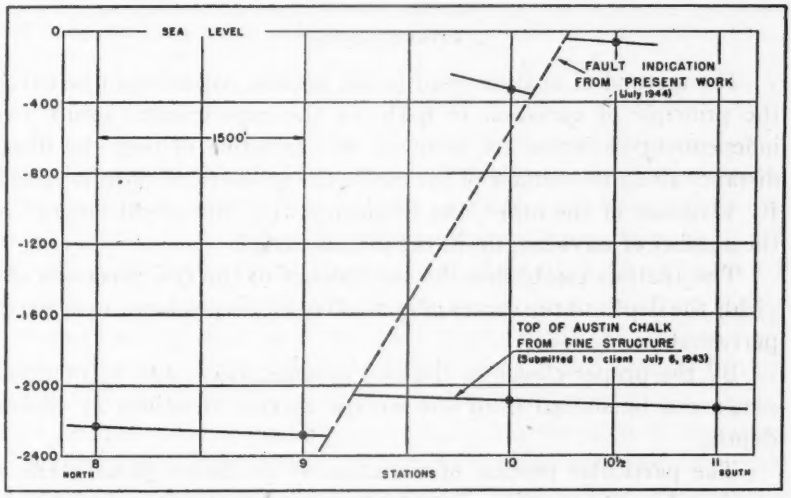


FIG. 1. Indication of fault in Austin Chalk, deduced from interpretation of electrical fine structure, and indication of fault in shallow electrical marker, deduced by application of principle of variation in path.

Emma Dibrell Est. #1, was drilled in this area, based exclusively on electric structure evidence. The Austin Chalk in this hole was found to be 18 feet higher than predicted by the electric survey. This older work was based on the "fine structure" in the electric dispersion graphs. The process of interpretation in this technique is similar to that of seismograms and requires an element of personal judgment and skill which is unfortunately rare. The method described in this paper, on the other hand, is a fully automatic process, requiring no special gifts except those of simple arithmetic.

In view of the fact that the previously submitted electric structure was checked quite well by the hole drilled at Emma Dibrell Est. #1, and since the structure computed in the present paper is located only a

short distance from this hole, we have in Fig. 1 shown the relation of the latter to the former. The relatively shallow fault indication obtained from the present work is seen to fit in logically with the deeper fault indication in the older work.

The relatively shallow electric marker indicated by the present work correlates in regard to depth, sign, and prominence with a conductor at a depth of 920 feet in the electric well log at Emma Dibrell Est. #1. The marker probably does not have any geologic significance on a regional scale but apparently serves to delimit structure locally.

CONCLUSIONS

The method of analysis used in the present paper might be called the principle of variation of path. In the experimental setup, two independent variables are involved. By variation of one, the linear distance along the surface of the earth, the geometrical path is varied. By variation of the other, the frequency, the "numerical length" or the number of wave lengths in the path is varied.

The analysis establishes the equivalence of the two processes and yields the depth to the center of symmetry of the predominant electric perturbation.

By the proper choice of the two parameters, x_0 and f_0, predominance can be shifted from one electric marker to others at various depths.

The particular process of variation of the linear parameters, x, employed in this paper, was used because it entails a simple field procedure. From the theoretical standpoint a lateral displacement, in which x is zero and y is varied, is much simpler because only the tangential component of the electric vector then comes into play and the solution of the functional equation involves only first order partial derivatives.[3]

From the point of view of accuracy in working up the data this lateral displacement has a decided edge, but the field procedure is cumbersome.

Both in regard to structural exploration and direct detection of oil, this new principle of path variation appears to hold considerable promise.

[3] The solution, in fact, becomes,

$$r^2 = x^2 + y^2 = -y\left(3P - 2f\frac{\partial P}{\partial f}\right)\Big/\frac{\partial P}{\partial y}.$$

THERMODYNAMICS OF A GAS MIGRATING VERTICALLY THROUGH THE SEDIMENTARY COLUMN*

R. MAURICE TRIPP†

ABSTRACT

The gaseous hydrocarbons in a petroleum trap which escape to the surface by diffusing through the semi-permeable geologic column are viewed thermodynamically to see if there might be an energy transfer involved that could produce a significant shift in the chemical, physical, or biologic equilibrium of the local environment.

INTRODUCTION

It has long been observed that a metalliferous ore body tended to upset the normal chemical, physical, and biological equilibrium in its immediate environment. Prospectors seeking ore bodies learned to recognize certain of these equilibrium shifts and found them to be invaluable aids. For instance, the oxidation of a sulfide ore produces an increase in the hydrogen ion concentration of the soil solution which may reach as high a pH as 2 or 3, particularly where the ore is high in pyrite and is relatively young. An abnormal acid environment of this nature will not permit the normal micro-organic population to exist. Most plants also have a definite and usually narrow range of tolerance to hydrogen ion concentration. Therefore the presence of certain plants becomes indicative of local mineralization. Further, the oxidation of pyrite with the formation of iron sulfate is followed by an hydrolysis and separation of the relatively insoluble iron hydroxide. The iron in this form is colloidally dispersed and bears an electropositive charge which can be neutralized by the electronegative kaolin particles resulting from the decomposition of the feldspars. Neutralization is accompanied by co-flocculation of both colloids and the formation of an impervious "iron pan" near the surface. Other variables such as the texture of the soil crumb, the color, the organic matter content, or the configuration of the topography are some of the additional criteria which may be abnormal.

In some instances, similar readjustments in equilibrium conditions have been observed around petroleum accumulations. Undoubtedly

* Presented at the fourteenth annual meeting in Dallas, Texas, March 1944, as part of *A Radon Survey of the Fort Collins Anticline.*

† Laboratory, Geotechnical Corporation, Cambridge, Massachusetts.

there must be many upset equilibrium balances which have never been properly recognized.

The purpose of the following discussion is to reduce certain factors concerned with a petroleum accumulation to mathematical entities insofar as possible so as to permit a quantitative analysis. An optimistic interpretation of this analysis suggests some interesting parameters by which a petroleum deposit might be recognized. Preliminary investigations concerned with determinations of the anomalous equilibrium conditions of two of these parameters have been reported elsewhere in this journal.[1]

The thermodynamic viewpoint was first suggested by Nisle.[2] The excuse for the present paper is the introduction of some additional factors which alter the conclusions that may be drawn.

The analysis is intended to be quite specific; therefore is confined to the environmental conditions of the Fort Collins structure. The subsequent field work was carried out in this area also.

The pertinent features concerned with the geology of the Fort Collins Anticline have been discussed previously[3] and will not be repeated here.

OBJECTIVE

It is desired to study the thermodynamics of a light hydrocarbon gas when it diffuses from the high pressure reservoir through the semipermeable geologic column to atmospheric pressure at the surface, and to determine the influence which this action has upon the chemical, physical, or biologic equilibrium of the formations traversed.

ASSUMPTIONS

1. Since methane is the predominant hydrocarbon in natural gas, the physical parameters of methane will be applied to the entire mixture and the calculations will be carried out as though methane and H_2O vapor were the only two components.

2. The migration takes place by diffusion through a medium of low permeability at such a rate that the gas is in thermal equilibrium

[1] Tripp, R. M. *Analytical and Experimental Data Concerning a Solid Hydrocarbon Survey of the Fort Collins Anticline.* GEOPHYSICS, Vol. 9, No. 3 (July 1944).

Tripp, R. M. *Measurement of Soil-Air Ions Over the Fort Collins Anticline,* GEOPHYSICS, Vol. 10, No. 2, pp. 238–247 (April 1945).

[2] Nisle, R. G. *Considerations on the Vertical Migration of Gases.* GEOPHYSICS, Vol. 6, No. 4 (Oct. 1941).

[3] Tripp, R. M., GEOPHYSICS, Vol. 9, No. 3, p. 378 (July 1944).

with its surroundings at all times and the reaction may be considered reversible.

3. A mean geothermal gradient was calculated from temperature measurements in wells on the Fort Collins anticline and found to equal .0337°F/ft.[4]

4. The mimimum pressure gradient possible, that of hydrostatic conditions, .45 lb/in²/ft. of depth, was assumed.

5. The methane is considered saturated with water vapor at all times.

6. The gaseous mixture obeys the gas law $PV = nZRT$.

7. The migration is so slow that friction losses are negligible.

8. The mol fraction of H_2O vapor is so small that Dalton's law for gaseous mixtures, $p = p' - p''$, in which p' is the partial pressure of methane and p'' is the vapor pressure of H_2O, was not considered a necessary correction. The pressure of methane was taken equal to the total pressure of the mixture.

ANALYSIS

The rate of flow of the gas through the semi-permeable rocks may be represented by a modified D'arcy's equation provided the pressure decline is not too rapid. The equation is as follows:

$$Q = \frac{KA}{\mu(1+m)L_n}\left[p_1^{1+m} - p_n^{1+m}\right]$$

where Q = flow of gas in cubic centimeters per second
K = permeability in darcys
A = cross sectional area of flow in cm²
μ = viscosity of gas in poises
m = the thermodynamic character of expansion of the gas; for isothermal $m = 1$, for adiabatic $m = c_v/c_p$
L_n = distance from reservoir to surface in cm.
p_1 = reservoir pressure in atmospheres
p_n = partial pressure of gas at surface in atmospheres.

As shown previously,[5] a conservative numerical solution of this equation indicates that 376 cubic feet of methane are diffusing to the

[4] Well temperatures published in *Handbook of Physical Constants*, Geol. Soc. of Amer., F. Birch (editor), 1942.

[5] Tripp, R. M., *ibid.*

surface per square yard per year. If this is considered to be the volume at the surface under mean conditions of temperature and pressure, the rate of diffusion may be expressed as 3,975 mols of CH_4 per acre per year.

Table I presents the results of calculations to determine the amount of water vapor contained by the methane gas at any point along its path of migration.

TABLE I. H_2O VAPOR EVAPORATED FROM THE CONNATE FLUIDS BY .3045 MOLS OF CH_4 MIGRATING THROUGH THE SEDIMENTARY COLUMN UNDER A PRESSURE GRADIENT OF .0306 ATMOS/FOOT AND A THERMAL GRADIENT OF .0337°F/FOOT.

Depth in feet	Temp. °F	Abs. P. Atmos.	Comp. Factor Z	Relative Vol. of CH_4 in feet³	Mol Fract. H_2O	Total Vol. H_2O ft.³×10³	Interval Evaporation ft.³×10³
1	2	3	4	5	6	7	8
0	52.6	.816	.999	139.3	.0170	2370.	+1158.
10	53.0	1.122	.997	101.1	.012	12.12	+761.
25	53.5	1.578	.996	71.5	.0063	451.	+179.
50	54.4	2.343	.995	48.5	.0056	272.	+170.
100	56.0	3.88	.991	29.2	.0035	102.	+76.
250	61.5	8.46	.983	13.4	.00195	26.1	+15.6
500	70.4	16.10	.971	7.11	.00147	15.5	+5.2
1000	86.2	31.40	.948	3.66	.00145	5.3	+0.5
1500	104.0	46.75	.934	2.50	.00192	4.8	−0.3
2000	120.0	62.0	.926	1.92	.0027	5.1	−0.4
2500	137.7	77.4	.922	1.58	.0035	5.5	−0.5
3000	153.6	92.6	.924	1.36	.0044	6.0	−0.7
3500	171.2	107.9	.929	1.20	.0056	6.7	−0.9
4000	187.3	134.2	.933	1.09	.0070	7.6	−1.9
4500	205.0	138.5	.938	1.00	.0095	9.5	

Column one indicates the depth in feet below the surface. Production at Fort Collins comes from the Muddy Sand at a depth of 4500 feet. Column two contains values for the temperature at the respective depths calculated from the mean geothermal gradient of .0337°F./foot of depth and a mean soil temperature of 52.6°F. Colunm three contains values for the pressure at the respective depths in atmospheres absolute. Subsurface pressures were calculated by taking the mean atmospheric pressure of .816 atmospheres and a mean gradient of .0306 atmos/foot of depth.

Values in column four were taken from a family of constant temperature curves plotted with pressure as the ordinate and compressibility factor as abscissa. Data for these curves was obtained from the work of Buderholzer, Sage and Lacey.[6] The experimental work was per-

[6] Buderholzer, Sage and Lacey. *Phase Equilibria in Hydrocarbon Systems.* Table III. Jour. of Ind. & Eng. Chem. vol. 31, p. 369.

formed over the pressure range 0–1500 lbs/in² absolute and at temperatures from 70°F. to 220°F. in 30° intervals. The curves were extrapolated up to a pressure of 2200 lbs/in² absolute and the desired values of compressibility factors interpolated theref om.

The figures in column five were arrived at by solving the gas equation $PV=nZRT$. For the sake of convenience one cubic foot has been taken as the volume-unit of gas in the reservoir which in that environment is .3045 mols. All other volumes were calculated on that basis and are relative with respect to a unit volume at reservoir conditions.

Column six is a listing of the mol fraction of water vapor contained by the methane at the temperature and pressure conditions existing at the respective points along the stratigraphic column. These values were interpolated from a family of constant temperature curves found by plotting the absolute pressure as ordinate and mol fraction of H_2O vapor as abscissa from the experimental data of Olds, Sage and Lacey.[7] The limited range of pressures in the low temperature region and the large rate of change in composition in the low pressure range make it necessary to express the data from this table in the form of a ratio of the product of the mol fraction of water and the pressure, to the vapor pressure of water at the temperature in question. The plot of this ratio as ordinate against pressure as abscissa gives a set of straight line constant temperature curves which converge to the ratio one at zero absolute pressure.[8] These constant temperature curves may be reliably extrapolated below and above the experimental pressure range. Values for the mol fraction of H_2O vapor in the methane-water mixture were then calculated from the "ratio" coordinate in the low pressure range desired. The results were values of the mol fraction of water at equal intervals of pressure for constant temperatures of 100°, 160°, 220° and 280°F. By plotting these data on double logarithmic paper the resulting curves approach straight lines. Since the temperature range of greatest value was between 50° and 100°F. it was necessary to extrapolate the data into this region. This was accomplished by interpolating from the available data and constructing a new set of curves at equal temperature intervals of 50°F. The result was a family of curves which were separated from one another by a distance which followed a geometrical progression increasing toward lower

[7] Olds, Sage, and Lacey. *Phase Equilibria in Hydrocarbon Systems.* Table I, Jour. of Ind. & Eng., Chem., Vol. 34, p. 1223.

[8] See reference 7 for complete details of reduction method.

temperatures. The 50°F. line was then drawn so as to satisfy the progression.

The lowest available pressure was 200 lb/in² and it was desired to carry the calculations down to 12 lbs/in². To do this the curves were extrapolated in the following mnaner. The vapor pressure for H_2O at the desired temperature was divided by a pressure of one atmosphere. If the Dalton's law correction is neglected, the result is the mol fraction of H_2O vapor at a pressure of one atmosphere and the specified temperature. With this control point the trend of the curves from pressures above 200 lbs/in² were extended down to 10 lb/in² with considerable reliability, particularly since the curvature is small when plotted on double logarithmic coordinates.

Column seven was obtained by multiplying column five by column six and shows the actual volume of H_2O vapor in the mixture in cubic feet at the conditions stated.

Column eight gives the volume of H_2O vapor evaporated from the formation through the interval indicated by column one. A negative prefix indicates that water is being condensed from the gas and a positive prefix that water is being evaporated from the formation.

With information on the rate of flow of the gas and its water vapor content along the path of migration, it can be calculated that 25,100 cubic feet of H_2O vapor are being evaporated from the upper twenty-five feet over an area of one acre in a year's time.

Consider now the energy transfer involved when a gas expands through a permeable medium to a new environment of temperature and pressure.

The enthalpy of methane at a temperature of 205°F. and one atmosphere of pressure is the mean heat capacity between 0° and 665°R multiplied by the temperature 665°.

Mean $C_p = 8.33 - (.0053/2) \times 205 = 8.873$ BTU's/lb-mol/°F.

$H_1 = C_p \times T - 8.873 \times 665 = 5900$ BTU's/lb mol

However, the methane is at a pressure of 138.5 atmospheres instead of one atmosphere. The correction necessary because of the elevated pressure may be determined from the relation,[9]

$$R\left(\frac{\delta \ln \gamma}{\delta \ln T_r}\right) = \frac{\Delta H^*}{T}$$

[9] Values of $\left(\frac{\delta \ln \gamma}{\delta \ln T_r}\right)$ have been determined by Watson and Smith and reported in National Petroleum News, July, 1936.

where γ = activity coefficient
T_r = reduced temperature
T = absolute temperature
R = gas constant

Reduced temperature at 205°F. = 665/343.5 = 1.94
Reduced pressure at 138.5 atm. = 138.5/45.8 = 3.02
$\Delta H^* = .99 \times 665 = 658$ BTU's/lb. mol

This correction must be subtracted from the enthalpy at 205°F. and one atmosphere to obtain the enthalpy at 205°F. and 138.5 atmospheres pressure.

$$H' = 5900 - 658 = 5242 \text{ BTU's/lb. mol}$$

The enthalpy at 52.6°F. and one atmosphere is similarly determined as,

$$H_2 = C_{p(\text{mean})} \times T = 8.469 \times 512.6 = 4350 \text{ BTU's/lb. mol}$$

The correction from one atmosphere to .8 atmospheres is not significant.

The change in enthalpy in going from a temperature of 205°F. and 138.5 atmospheres to a temperature of 52.6°F. and .82 atmospheres may be written

$$H = H' - H_2 = 5242 - 4350 = 892 \text{ BTU's/lb. mol}$$

A loss of 892 BTU's/lb. mol of methane would produce a temperature drop in the gas of $892/8.33 - .0053/2(205 - 52.6) = 101.8$°F. The actual drop in temperature amounts to $205° - 52.6° = 152.4$°F. The increase of the actual drop over the drop due to the expansion process must be caused by the heat lost in evaporating water from the connate fluids or by heating the surrounding rock. An inspection of Table I indicates that the total H_2O evaporated amounts to 4.97×10^{-3} lbs/mol of CH_4 and the total H_2O condensed from the gas amounts to $.982 \times 10^{-3}$ lb/mol of CH_4 or a net evaporation of 3.982×10^{-3} lbs/mol of CH_4.

An exact solution of the heat balance involved would require that a summation be taken of the heat absorbed by the gas when an increment of H_2O is condensed at its respective temperature subtracted from the summation of heat removed when an increment is evaporated at its respective temperature.

A reasonable approximation may be made to avoid such a laborious calculation since 81 per cent of the H_2O evaporated comes from the upper 25-foot zone. It will be assumed that all the water evaporated does so at the mean temperature in this interval. Likewise 80.7 per

cent of the H_2O vapor which is condensed does so in the lower 1500 feet. It will be assumed that all the H_2O is condensed at the mean temperature of this interval.

Heat absorbed by one mol of methane resulting from the condensation of $.982\times10^{-3}$ lbs. of H_2O/mol of CH_4 at a mean temperature of 179.3°F. $=553.2\times1.8\times.982\times10^{-3}=.98$ BTU's.

Heat lost by one mol of methane resulting from evaporation of 4.97×10^{-3} lbs. of H_2O/mol of CH_4 at a mean temperature of 53.°F. $=589.5\times1.8\times4.97\times10^{-3}=5.27$ BTU's.

Net loss of heat by one mol of $CH_4=5.27-.98=4.29$ BTU's, or a drop in temperature of $4.29/8.33+[(.0053/2)(53°)]=.506$°F.

The cooling produced by expanding through the sediments, 101.8°F., plus the cooling resulting from evaporation of the H_2O vapor, .506°F., is not sufficient to account for the actual cooling which takes place, 152.4°F. The additional heat, $(152.4-102.3)\times[8.33+(.0053/2)(205-52.6)]=437$ BTU's/mol of CH_4, must be dissipated to the rock through which the gas passes, producing a slight rise in temperature and change in the local geothermal gradient.

CONCLUSIONS

The fact that the moisture content passes through a minimum when the water saturated methane migrates vertically and then increases rapidly toward the surface is of more than passing interest. Eight-one per cent of the total water evaporated from the 4500 feet of formation fluids is removed from the upper 25 feet. This might produce a measurable temperature anomaly in the rocks near the surface in the immediate vicinity of the flux lines. Therefore the presence of anomalous temperature gradients in the near surface zone might be indicative of petroleum at depth. Furthermore, the removal of appreciable quantities of ground water might cause the concentration of certain extremely insoluble compounds which are dissolved in the ground water to reach their solubility product and be precipitated. These less soluble minerals would be precipitated in the existing pores and tend to decrease the porosity. A process of secondary cementation such as this could alter the chemical, physical and/or the electrical properties of the near surface formations. Some aspects of secondary mineralization are treated in another paper.[10]

The possibility exists that a subsurface accumulation of petroleum

[10] Tripp, R. M. *Measurement of Soil-Air Ions Over the Fort Collins Anticline*, GEOPHYSICS, this issue, pp. 238–247.

might be indicated by measuring variations in the electrical resistivity at shallow depths, the lateral gradient of seismic velocities in the weathered layer, or by careful determinations of the geothermal gradient.

It is highly probable that in many instances these anomalies are very small and that other extraneous processes produce even greater variations of the property being considered. These anomalies have been found over several structures, but usually they can be adequately explained by other means.

MEASUREMENT OF SOIL-AIR IONS OVER THE FORT COLLINS ANTICLINE*

R. MAURICE TRIPP†

ABSTRACT

The soil solution is examined for compounds of very low solubility product which might exist in a state of saturation over a large area; some radioactive compounds are found to fill this requirement better than any others. It is postulated that these minerals are preferentially precipitated in the interstices of the near surface soil by the evaporation of the soil water caused by the passage of gaseous hydrocarbons escaping from their subsurface reservoir. Measurements of the rate of formaton of ions in the soil air over a producing structure are presented.

INTRODUCTION

In a paper appearing elsewhere in this journal[1] a study was made of the changes produced in the formations overlying a petroleum accumulation when gaseous hydrocarbons escape to the surface. This study indicated that for the Fort Collins Anticline, the vertically migrating gas contained decreasing amounts of water vapor as it ascended from 4500 feet to 1000 feet. From the 1000-foot depth to the surface the amount of water vapor contained by the original quantity of gas increased exponentially. The most interesting fact, however, is that 81 per cent of all the water evaporated from the formations is removed from a vertical zone between the surface and a depth of 25 feet. A conservative calculation indicated that a minimum of 25,100 cubic feet of water vapor would be evaporated from the upper 25-foot zone per year over an area of one acre.

GENERAL CONSIDERATIONS

Twenty-five thousand cubic feet of water vapor does not represent a large quantity of water to be removed when viewed with respect to other variations in the zone, but it suggests that perhaps certain constituents of the soil solution which have a very low solubility product or which exist as hydrophillic colloids with small zeta potentials might be locally precipitated. As a consequence of the evaporation, small decreases in the volume of the soil solution would tend to increase the

* Presented at the fourteenth annual meeting in Dallas, Texas, March 1944, as part of *A Radon Survey of the Fort Collins Anticline.*

† Laboratory, Geotechnical Corporation, Cambridge, Massachusetts.

[1] Tripp, R. M. *Thermodynamics of a Vertically Migrating Gas Through the Sedimentary Column,* GEOPHYSICS, this issue, pp. 229–237.

concentration of the dissolved compounds and if the solubility product were exceeded precipitation in the formation pores would result. Also changes in the ion concentration could neutralize the potential on colloidally dispersed substances, or in the extreme case produce flocculation by dehydration.

It should be appreciated that this evaporation is a continuous process so that even if fluctuating ground water were moving laterally in the region, the area through which the gas is passing will always be slightly more concentrated than adjacent areas. Therefore the concentrating effect is partially cumulative, especially where non-reversible colloids are flocculated.

With the above considerations in mind, the soil solution was examined for the presence of compounds of extremely low solubility which might have a chance of occurring over a large area and at the same time be amenable to accurate analysis in very low concentrations.

Several compounds were found which answered these requirements with varying degrees of satisfaction, but certain compounds of the radioactive elements appeared to be far better than the others. The preference resulted from the fact that all rocks contain some radio-elements with the possible exception of salt and sulfur. The weathering of the rocks when exposed at the earth's surface results in a surficial concentration of the radioactive minerals in the normal soil profile as a result of the leaching away of other more soluble minerals. This tends to insure an abundance of undissolved material in the soil horizon and in turn a concentrated condition of the soil solution. In addition, certain compounds of the radioactive elements have a tendency to form metastable colloidal dispersions in neutral or slighty acid solution producing a sol with a very low zeta potential. Furthermore methods are available by which extremely small concentrations of radioactive material may be quantitatively determined, and it is possible to make these measurements in the field without sacrificing too much in accuracy.

FIELD METHODS

Field measurements consisted of a determination of the rate of formation of ions in a unit volume of soil air at the selected stations. Samples of air were taken from the "B" horizon of the soil profile as shown in Fig. 1.

An absolute determination of the amount of radioactive material

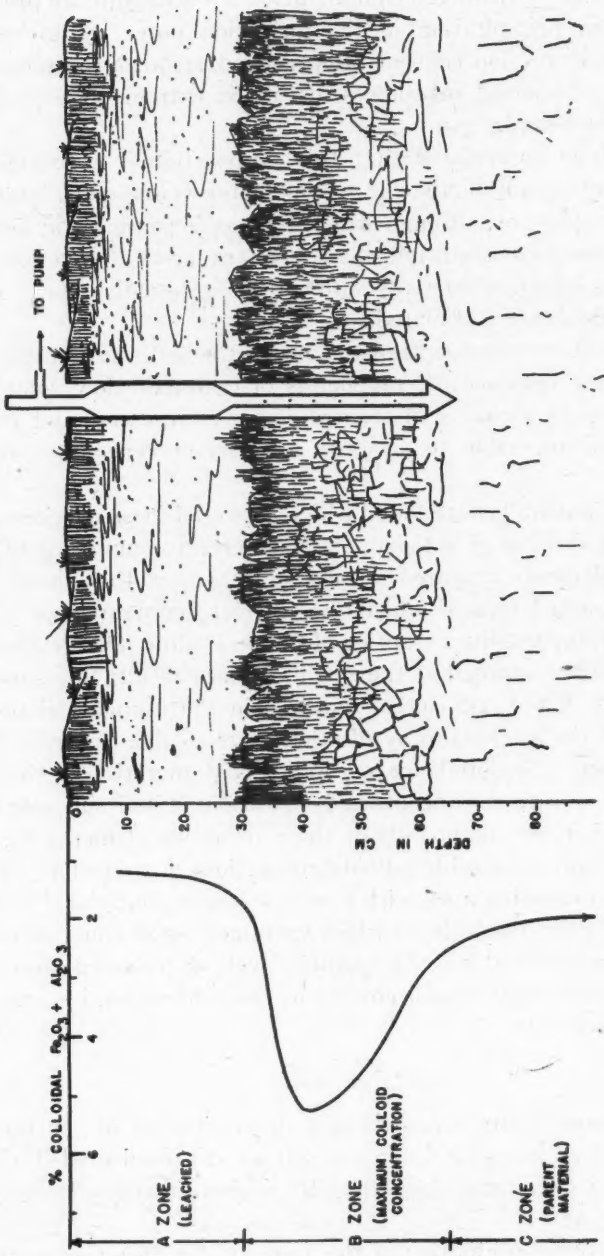


FIG. 1. Normal soil profile and the method of sampling soil air.

in the soil profile would not be of any greater significance than the relative amounts at various points over the prospect. Therefore no attempt was made to calibrate the instrument in absolute units.

The ionization produced in the chamber is the sum total effect of the alpha radiation from radon, thoron, actinon, and their respective active deposits.

The soil-air sample was removed from the soil through a specially designed tube which prevented contamination from the atmospheric air, then dried by passing through calcium chloride and magnesium perchlorate, and pumped into a 1292 cubic centimeter ionization chamber equipped with a unifilar electrometer. The electrometer was charged to a predetermined voltage by means of "B" batteries and the time required for the voltage to drop through a specified interval was measured with a stop watch. At least two runs were made at each station.

From the discharge time, the volume of the chamber, and the measured electrostatic capacity of the ionization chamber it is possible to calculate the rate at which ions are being formed in the sample of soil gas.

The ionization current in the chamber may be obtained from the following expression:

$$i = 3 \times 10^{-3} f\, dv/dt$$

where i = the ionization current in statamps

f = capacity of the chamber in micromicrofarads

dv/dt = rate of change of potential in statvolts per second

From this it is possible to determine the number of ion pairs formed per cubic centimeter per second,

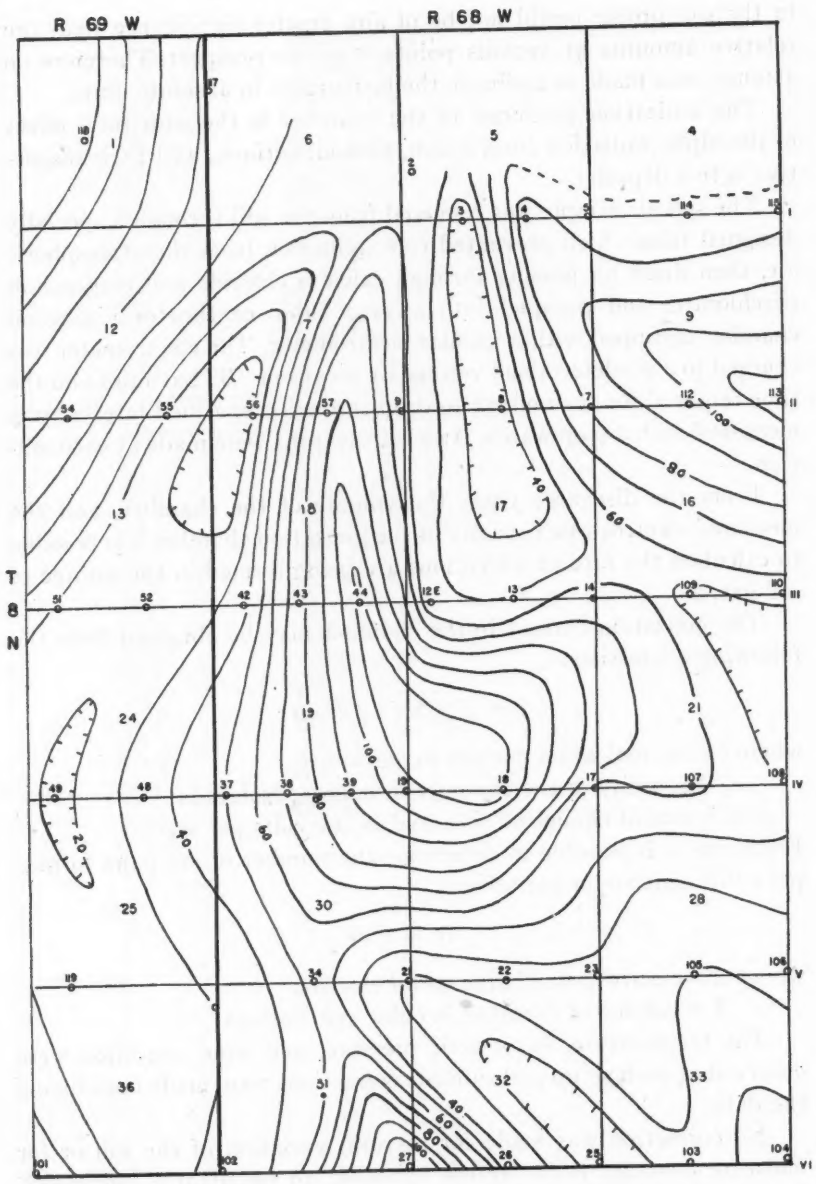
$$N = i/eV$$

where e = electrostatic charge on an electron

V = volume of chamber in cubic centimeters

The temperature, barometric pressure, and wind condition were observed at each setup and suitable corrections were made in reducing the data.

No correction was made for textural variation of the soil or for moisture content. Both factors appeared to be slightly influential. Damp soils generally showed a higher value than the equivalent dry soil. Such a condition would be predicted from the property of radium salts to liberate radon more readily when in solution than when dry.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On the other hand, stations near bodies of water where the water table came near the surface showed abnormally low values; probably the result of ground water leaching.

Stations which were reoccupied at successive intervals over a period of several days or weeks checked very well.

Table I is a summary of results obtained by this method over the Fort Collins Anticline.

TABLE I. RATE OF IONIZATION OF THE SOIL AIR AT STATIONS OVER THE FORT COLLINS ANTICLINE

Station No.	Ions/cc/Sec	Station No.	Ions/cc/Sec
2	76.2×10^8	44	111.0×10^8
3	33.4	48	34.8
4	87.4	49	17.6
5	73.0	51	28.1
7	81.1	52	28.1
8	32.9	54	73.6
9	63.4	55	24 3
12E	47.5	56	18.7
13	50.8	57	91.2
14	65.5	101	44.2
17	57.1	102	24.7
18	111.3	103	31.3
19	106.0	104	14.4
21	26.8	105	28.2
22	35.8	106	32.0
23	37.0	107	63.6
25	12.2	108	49.2
26	49.3	109	47.9
27	113.5	110	52.1
29	41.6	112	87.2
31	30.2	113	114.8
34	50.6	114	182.3
37	50.0	115	73.0
38	70.6	117	76.2
39	75.8	118	146.0
42	34.9	119	27.1
43	78.2		

The values of ionization rate in Table I may be plotted on a map at the point the soil-air samples were taken and the results contoured to obtain an iso-ion map of the area. Fig. 2 is such a map, which is to be compared with the structural map of Fig. 3.

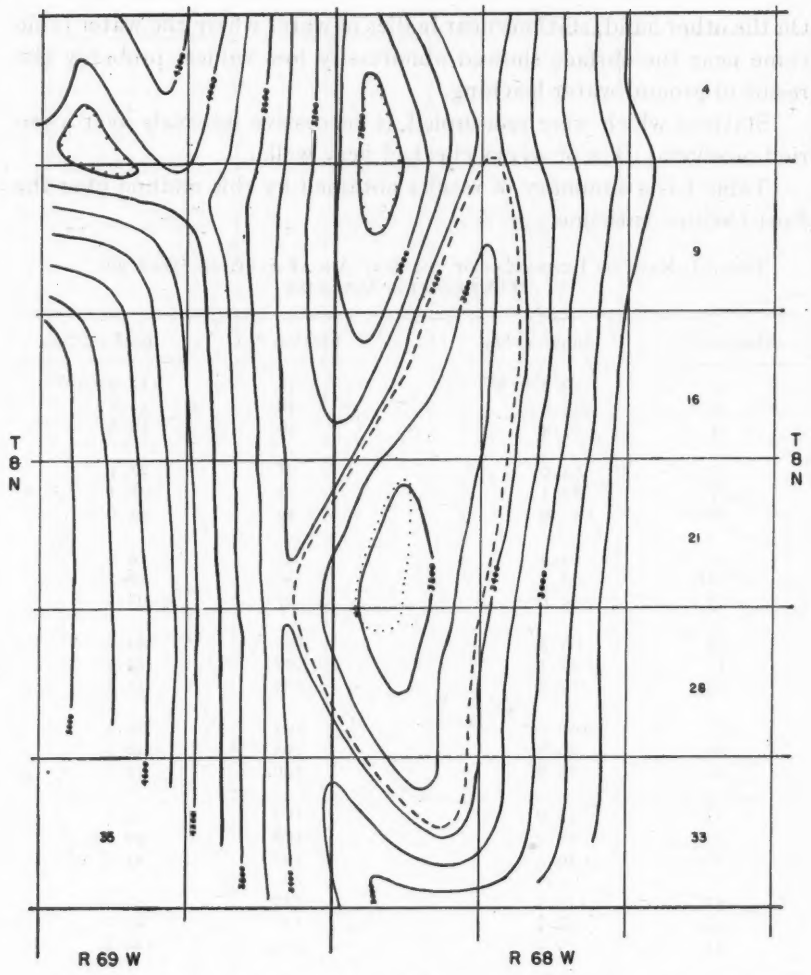

FIG. 3. Structural map of Fort Collins Oil Field, Larimer County, Colorado. Contoured on sandstone member of Pierre shale by A. T. Schwennesen. Contour interval equals 200 feet.

DISCUSSION

The foregoing discussion suggests that the vertically migrating gas from a subsurface reservoir which evaporates water from the near surface zone might cause a concentration of the dissolved matter in the soil solution accompanied by a precipitation of the more insoluble compounds and/or a flocculation of certain colloids of low zeta poten-

tial. Since some radioactive minerals fall within this classification, the possibility exists that the measurement of the radioactivity of the soil colloid might reveal an anomalous high where the rate of gas leakage is greatest. Furthermore, the alpha radiation associated with the radioactive minerals may have an effect upon the hydrocarbon gas adsorbed on the soil particles or mixed with the radon gas in the soil air. This hypothesis has been discussed more fully in a previous paper[2] and will only be summarized here.

Lind and his associates[3] showed several years ago that hydrocarbons were readily ionized by alpha-radiation from radon with the subsequent formation of double ion clusters which condense to form larger hydrocarbon molecules. The larger molecules are in turn ionized by direct impact or electron transfer to form new clusters which result in larger heavy molecules, accompanied by the liberation of free hydrogen and methane. This process may continue until the gaseous members become liquid and those in turn become long chain solids. This reaction, if not the mechanism, has been verified by recent experiments in other laboratories.

If we accept the possibility of the above reaction proceeding in the soil environment, a soil-ion anomaly resulting from subsurface petroleum should be mutually related to a solid hydrocarbon anomaly. Either of the quantities may become anomalous for reasons which have no meaning in petroleum exploration, but when the two anomalies are mutually related they take on much greater significance as an exploration index.

Fig. 4 was prepared by contouring the values of soil wax concentration determined from samples collected at the same stations at which the ionization rate was determined. Fig. 5 permits a more direct comparison of the structural configuration, the ionization rate, and the solid hydrocarbon concentration along east-west profiles taken along the section lines.

A definite anomaly appears to exist over the structure, but the lack of coincidence between the "highs" is not in complete agreement with their suggested origin. Sufficient field data have not been gathered to permit any broad generalizations to be made.

[2] Tripp, R. M. *Analytical and Experimental Data Concerning A Solid Hydrocarbon Survey of the Fort Collins Anticline.* GEOPHYSICS, Vol. 9, No. 3 (July 1944).

[3] Lind, S. C. and Glocker, C. *Condensation of Hydrocarbons by Alpha Rays.* Jour. Amer. Chem. Soc. 52, p. 4450, 1930.

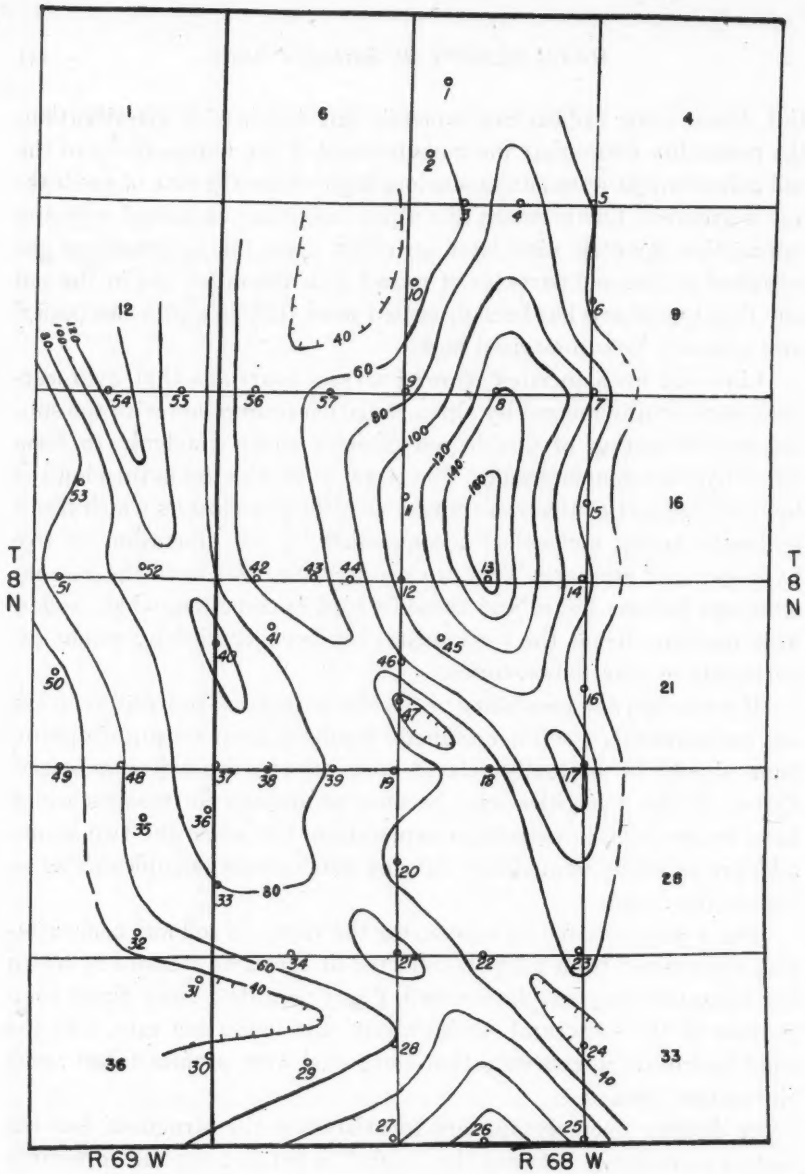

FIG. 4. Iso-wax contour map of Fort Collins Oil Field, Larimer County, Colorado. Contour interval equals 20 parts of wax per million parts of soil by weight.

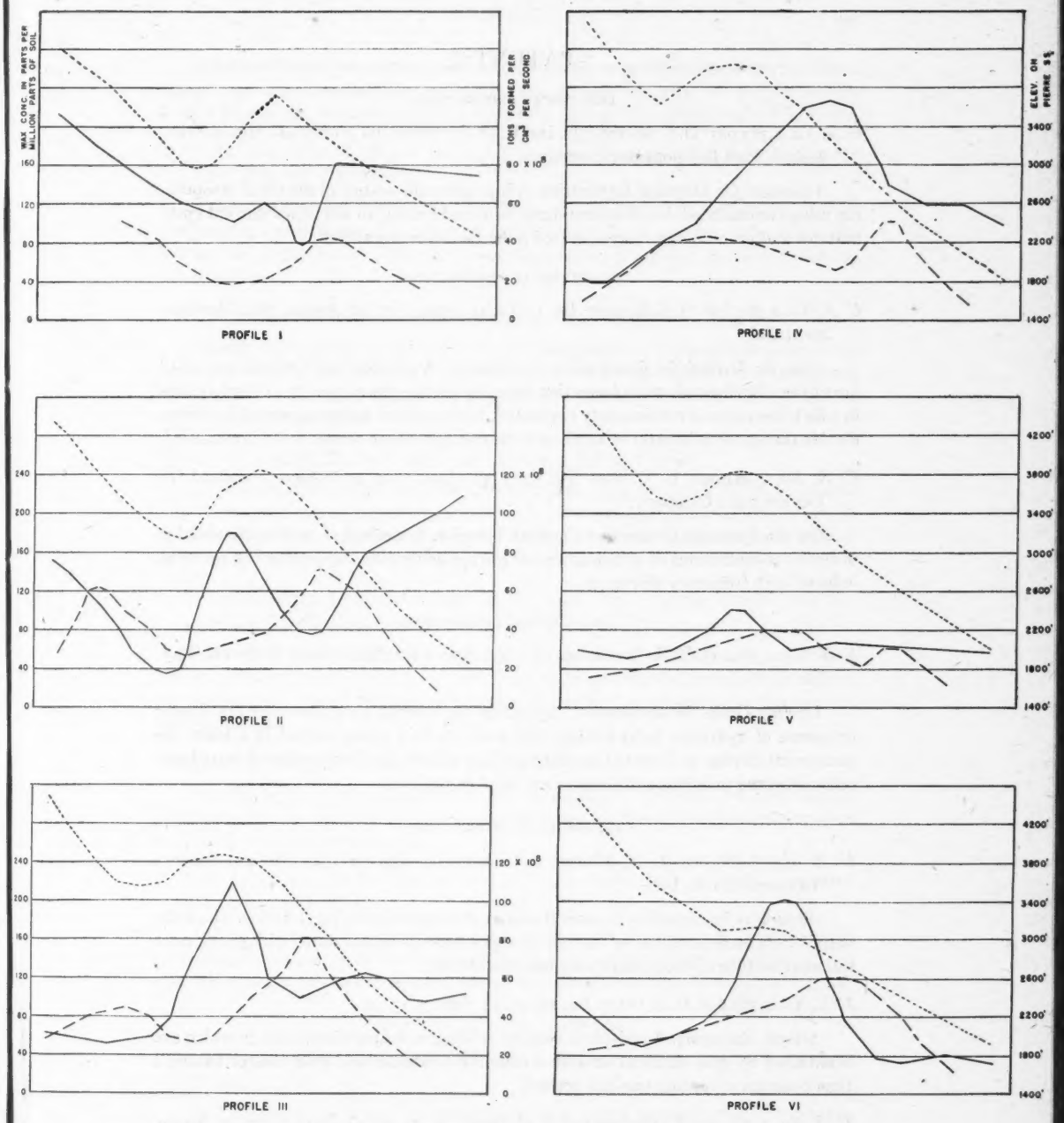

FIG. 5. Profile sections of ionization rate, soil wax concentration, and structure taken along the east-west section lines on the Fort Collins anticline, Profile VI being the southernmost line. The solid line is the ionization rate profile, the dotted line the structural profile, and the dashed line the soil wax profile.

PATENTS*

ELECTRICAL PROSPECTING

U. S. No. 2,363,987. D. S. Muzzey, Jr. and R. D. W. Miller. Iss. 11/28/44. App. 9/8/41. Assign. Shell Development Company.

Apparatus for Electrical Exploration. A four electrode system of electrical prospecting using commutated d-c of square wave form and having an electronic current commutator and synchronous relay operated potential reversing switch.

GEOCHEMICAL PROSPECTING

U. S. No. 2,364,898. G. L. Hassler. Iss. 12/12/44. App. 9/21/40. Assign. Shell Development Co.

Analysis Method for Geochemical Exploration. A method for determining small quantities of hydrocarbons in formation water by placing the sample in a closed system in which the vapor is continuously circulated, hydrocarbons being converted to carbon dioxide thence to carbonates in an electrolytic solution whose conductivity is measured.

U. S. No. 2,364,940. C. C. Bies. Iss. 5/12/44. App. 6/10/41. Assign. Standard Oil Development Company.

Gas Analysis and Combustion Chamber Therefor. A method of causing combustion of small concentrations of hydrocarbons in soil gas analysis by subjecting the gas to an induced high frequency discharge.

GRAVIMETRIC PROSPECTING

U. S. No. 2,362,135. P. H. James. Iss. 11/7/44. App. 12/19/40. Assign. Robert H. Ray, Inc.

Leveling Device for Gravimeters. Apparatus for leveling an underwater gravimeter by means of hydraulic jacks having fluid conduits to a pump carried in a boat, the instrument having an inverted pendulum which affects the illumination of two photocells connected to indicate the instrument level on the boat.

SEISMOGRAPH PROSPECTING

U. S. No. 2,360,507. J. P. Minton. Iss. 10/17/44. App. 10/1/41. Assign. Socony-Vacuum Oil Co., Inc.

Apparatus for Recording Seismic Waves. A seismograph mixing system in which the output from modulated carrier current type geophones is demodulated with one or more full wave rectifiers whose outputs are interconnected.

U. S. No. 2,361,648. O. S. Petty. Iss. 10/31/44. App. 5/15/40.

Seismic Surveying. A resistance coupled seismograph amplifier circuit in which avc is obtained by grid rectification with a coupling condenser and grid resistor having a time constant exceeding one-half second.

U. S. No. 2,363,303. K. Ehrgott and A. C. Hagg. Iss. 11/21/44. Appl. 7/31/42. Assign. Westinghouse Electric & Manufacturing Company.

* Abstracts by O. F. Ritzmann, Gulf Oil Corporation Patent Department.

Vibration Pickup. A moving coil electrodynamic type vibration pickup having a pair of opposing horseshoe magnets forming two air gaps and a flat coil having one side in each air gap and constrained by flat suspension springs to move only in one direction.

U. S. No. 2,363,985. W. Moser. Iss. 11/28/44. App. 2/24/40 and 5/15/41. Vested in Alien Property Custodian.

Automatic Volume Control Device. An avc circuit in which amplification is controlled by changing the grid bias of a tube, and having an auxiliary shunting tube whose bias is controlled in the opposite direction, so as to avoid any phase shift in the amplifier due to avc action.

U. S. No. 2,364,209. W. G. Green. Iss. 12/5/44. App. 8/14/43.

Seismic Prospecting. A high frequency continuous wave seismograph prospecting system in which a fluid immersed generator is driven by an oscillator and modulated by a condenser discharge and the pick-up signal is filtered and recorded along with the original modulating signal.

U. S. No. 2,364,655. H. H. Pratley. Iss. 12/12/44. App. 12/24/40.

Geophysical Exploration. An underground seismograph method of locating mineral deposits between mine workings in which the shot point and geophones are in tunnels on opposite sides of the region being investigated, and interpretation is made of a shadow effect.

U. S. No. 2,364,755. O. F. Ritzmann. Iss. 12/12/44. App. 1/22/42. Assign Gulf Research & Development Company.

Apparatus for Seismograph Prospecting. A system of automatically controlling the sensitivity or frequency of members of a group of seismograph amplifiers by taking the control from one of the channels having an earlier first arrival than the channel being controlled.

U. S. No. 2,365,289. O. S. Petty. Iss. 12/19/44. App. 5/15/40.

Seismic Surveying. An expander for controlling sensitivity with time on a seismograph record by increasing the galvanometer field current through sufficient inductance to give the proper expansion rate.

U. S. No. 2,366,043. W. D. Mounce. Iss. 12/26/44. App. 6/26/36. Assign. Standard Oil Development Company.

Automatic Gain Adjusting Device for Reflection Seismographs. An expander for controlling sensitivity with time on a seismograph record by increasing the galvanometer field current through a rheostat operated by a dash pot released on a first arrival.

WELL LOGGING AND SURVEYING

U. S. No. 2,359,894. H. Brown and H. S. Ribner. Iss. 10/10/44. App. 2/10/41. Assign. H. Brown.

Well Logging Method and Apparatus. A method of well logging in which current is passed between two ground electrodes equidistant from the well, and the resulting magnetic gradient in the well measured by means of two vertically spaced coils connected in opposition to an amplifier.

U. S. No. 2,360,041. C. R. Dale. Iss. 10/10/44. App. 7/26/43.

Apparatus for Subsurface Pressure Determinations in Wells. A device for determining fluid pressure in a well and consisting of a small tube which extends to the bottom and valves located at intervals along its length, a weight on a wire being dropped through the tube to open the valves in succession, and measuring the pressure required to discharge air through the valves.

U. S. No. 2,361,064. M. Schlumberger. Iss. 10/24/44. App. 12/29/42, 8/20/38 and 6/28/38. Assign. Schlumberger Well Surveying Corp.

Depth Measuring Apparatus. A device for determining when a cable suspended well tool leaves the bottom of a hole and having a plunger foot which when lifted off bottom opens an electric contact.

U. S. No. 2,361,261. J. G. Campbell. Iss. 10/24/44. App. 10/9/40. Assign. Ralph H. Fash.

Method of Detecting the Penetration of an Oil-bearing Horizon. A method of logging the fluorescence of drilling mud by taking samples of the same mud before and after circulation and comparing the ultra-violet fluorescence of an oil solvent layer placed on the surface of the samples.

U. S. No. 2,361,274. A. M. Cravath and G. L. Hassler. Iss. 10/24/44. App. 1/29/40. Assign. Shell Development Company.

Radiological Exploration System. A radioactivity logging apparatus in which ionization chamber signals are transmitted to the surface over the same cable by which d-c power is fed to the well apparatus by converting the d-c signals to a-c with an electrostatic alternator.

U. S. No. 2,361,389. R. E. Fearon. Iss. 10/31/44. App. 10/16/39. Assign. Well Surveys, Inc.

Well Survey Method and Apparatus. A method of measuring d-c ionization signals in radioactivity logging by converting them to a-c with a rapidly varying condenser and then amplifying the a-c.

U. S. No. 2,361,458. L. C. Converse. Iss. 10/31/44. App. 8/10/42. Assign. Standard Oil Development Company.

Microphone for Conduits. A microphone which may be used in logging a well or conduit to locate leaks or entry of fluid and having a rod mounted through a diaphragm, the outside end of the rod carrying a vane and the inside end contacting a microphone.

U. S. No. 2,362,164. D. Silverman. Iss. 11/7/44. App. 4/11/42. Assign. Stanolind Oil & Gas Co.

Radioactivity Logging. A method of radioactivity logging in which the ionization chamber current discharges a condenser which is automatically recharged through a thyratron, the frequency of this cycle being recorded at the surface as a measure of the radioactivity.

U. S. No. 2,362,805. R. L. Doan. Iss. 11/14/44. App. 6/17/40. Assign Phillips Petroleum Co.

Method and Apparatus for Detecting Hydrocarbons. A method of analyzing drilling mud for gas in which a sample is heated under pressure, then suddenly released with agitation into a vacuum chamber, the gases diluted with air, dried, and hydrocarbons detected by combustion on an incandescent platinum filament connected in a bridge circuit.

U. S. No. 2,363,793. M. C. Johnson. Iss. 11/28/44. App. 7/14/41.

Well Testing Apparatus. An electrically controlled side wall formation fluid tester having a series of nipples which are selectively forced against the formation and valves opened to admit fluid samples.

U. S. No. 2,364,088. H. C. Miller, W. R. Berwald and D. B. Taliaferro, Jr. Iss. 12/5/44. App. 7/31/40. Assign. U. S. Government.

Core Drilling. A drill stem pressure core barrel having a scavenging plug which moves up ahead of the core, each end of the barrel having a valve which may be operated by lifting the drill stem and lowering it to bottom.

U. S. No. 2,364,159. G. Muffly. Iss. 12/5/44. App. 10/11/40. Assign. Gulf Research & Development Company.

Apparatus for Electrical Bore Logging. An electrical dip and interface logging apparatus in which two a-c currents of different frequencies are supplied to current electrodes and the pick-up electrodes are connected to a filter which rejects applied frequencies so as to indicate modulation effects.

U. S. No. 2,364,464. T. V. Moore. Iss. 12/5/44. App. 5/4/42. Assign. Standard Oil Development Company.

Bottom Hole Sampler. A bottom hole pressure fluid sampler having two successive sealing discs, the outer one being punctured by a spear automatically released at a predetermined pressure and the inner one rupturing at a pressure below the formation pressure.

U. S. No. 2,364,957. N. Douglas. Iss. 12/12/44. App. 8/8/39. Assign Stanolind Oil and Gas Company.

Electrical Surveying. Apparatus for electrical logging while drilling and using oscillators at the bottom connected to the drill stem and an insulated drill bit and whose frequency varies with impedance and potential, and picking up the a-c potential at the surface between the drill stem and a ground electrode and recording the frequency.

U. S. No. 2,364,975. J. J. Heigl and L. R. Hodell. Iss. 12/12/44. App. 12/28/39. Assign. Standard Oil Development Company.

Determining Permeability of Geologic Structures. A method of determining the permeability of formations by adding a radioactive material to the drilling mud and subsequently running a radioactivity log.

U. S. No. 2,365,014. D. Silverman and R. W. Stuart. Iss. 12/12/44. App. 7/25/40. Assign. Stanolind Oil and Gas Co.

Apparatus for Drilling Rate Logging. A drilling rate recorder in which the longitudinal motion of the chart is proportional to depth and a transverse pen marking is proportional to the distance drilled in a unit number of drill rotations, the pen automatically returning to zero after each unit.

U. S. No. 2,365,763. B. J. Kalb and D. H. Wise. Iss. 12/26/44. App. 11/4/38 and 11/10/41. Assign. B. J. Kalb.

Well Logging Device. Apparatus for gamma ray well logging in which radioactive emanations from a source are directed at the formations and secondary radiations detected with an ionization chamber.

U. S. No. 2,365,999. F. G. Boucher. Iss. 12/26/44. App. 12/18/42. Assign. Standard Oil Development Company.

Borehole Inclinometer. A pendulum type remote indicating inclinometer in which the pendulum carries a light source whose displacement from the axis is recorded by using a photocell and a cam shaped rotating shutter which interrupts the light beam.

MISCELLANEOUS

U. S. No. 2,359,734. R. L. Hood. Iss. 10/10/44. App. 7/31/42. Assign. American Cyanamid Co.

Spectrophotometer Amplifier. A recording drive for a flickering beam infrared spectrophotometer in which the output from the opposing thermocouples is fed through a transformer, direct coupled amplifier, and thyratron tubes controlling relays which operate the recording pen motor.

U. S. No. 2,360,244. A. W. McAnneny. Iss. 10/10/44. App. 5/10/41. Assign. The Texas Co.

Anode for Cathodic Protection Systems. A method of preventing corrosion of anodes in cathodic protection systems by immersing the metal anode in an electrolyte in a porous container and adjusting the current density to set up a state of passivity in the anode.

U. S. No. 2,360,434. D. J. Manning. Iss. 10/17/44. App. 7/29/43.

Leak-Locating Apparatus. A device to be pulled through a gas line on an electric cable and which detects a water leak by the electrical conductivity between two electrodes separated by a dry salt impregnated pad.

U. S. No. 2,360,493. W. H. Harman, Jr. Iss. 10/17/44. App. 3/9/43. Assign. The Baldwin Locomotive Works.

Electrical Strain Responsive Apparatus. A filament type strain gage for small gage lengths and having three filament loops, one crossing the gage length and two approaching the gage length from either end, and connected in a bridge circuit so that only the part which crosses the gage length is not compensated.

U. S. No. 2,360,625. J. B. Walker. Iss. 10/17/44. App. 6/27/41.

Magnetic Recording Apparatus. A magnetic tape recording head in which one voice coil magnet pole is in contact with the moving tape and the other pole is adjustable on the same side of the tape but not in contact.

U. S. No. 2,360,751. H. Ziebolz. Iss. 10/17/44. App. 3/11/42. Assign. Electronbeam, Ltd.

Electronic Balance. A modified Kelvin balance in which movement of the balance lever magnetically or electrostatically deflects a cathode ray beam controlling an amplifier whose output is connected to restore balance.

U. S. No. 2,361,067. C. H. Shaw. Iss. 10/24/44. App. 8/18/43. Assign. American Smelting and Refining Co.

Ore Sampling Device. A sampling auger having an outer casing for the auger and having a hollow auger shaft through which air may be admitted when the auger and sample are withdrawn.

U. S. No. 1,361,173. T. E. Brown, Jr. Iss. 10/24/44. App. 3/24/43. Assign. Westinghouse Electric and Manufacturing Co.

Strain Measuring System. A measuring circuit for a single coil variable air gap reactance type strain gauge in which non-linearity is corrected by shunting the coil with a condenser sufficiently large to produce a leading power factor.

U. S. No. 2,361,349. R. K. Frazier. Iss. 10/24/44. App. 4/9/42. Assign. Bendix Aviation Corp.

Vibration Indicator. A vibration amplitude indicator in which the visual perception of a moving striped triangular figure is compared with a scale.

U. S. No. 2,361,622. R. J. Goulet. Iss. 10/31/44. App. 11/16/40. Assign. One-half to Coulter W. Jones.

Blasting Cartridge. A dynamite cartridge having a string fastened near one end with which the fuse may be tied in place.

U. S. No. 2,361,752. S. D. Eilenberger. Iss. 10/31/44. App. 2/22/43. Assign. Wolgen Co.

Magnetic Recording and Reproducing System. A magnetic recording head for grooved disk or cylinder recorders and having a non-magnetic shoe which engages several tracks to avoid wear on the pole tip.

U. S. No. 2,361,753. S. D. Eilenberger. Iss. 10/31/44. App. 2/22/43. Assign. Wolgen Co.

Magnetic Pole Piece. A magnetic recording head in which the magnet pole is sheathed with a slotted non-magnetic material which prevents wear on the pole tip.

U. S. No. 2,361,788. J. J. Neff. Iss. 10/31/44. App. 8/2/43. Assign. Jack & Heintz, Inc.

Displacement Pickup. A displacement pickup for surface finish testing and having an armature mounted centrally between an a-c energizing coil and two pick up coils and measuring the a-c unbalance in the pickup coils with a vacuum tube voltmeter.

U. S. No. 2,361,794. R. C. Pryor. Iss. 10/31/44. App. 1/22/43. Assign. Phillips Petroleum Co.

Seal for Subsurface Pressure Gauges. A piston seal for a bottom hole pressure gauge in which the stuffing box is oversize and the packing ring is split and forced into a barrel shape by the retainer plug.

U. S. No. 2,361,844. W. L. Horner. Iss. 10/31/44. App. 1/3/38 and 12/27/41. Assign. Core Laboratories, Inc.

Method for Determining Fluid Contents of Solids. A method of determining the free water and oil content of a core sample by supplying heat at a constant rate and measuring the water condensate when the rate of condensation first stops and measuring the total amount of oil condensed.

U. S. No. 2,361,915. H. Allen. Iss. 11/7/44. App. 12/23/40. Assign. Cameron Iron Works, Inc.

Weight Indicator. A dial type weight indicator in which the wire line is misaligned and the straightening tendency is measured by an elastic lever system which turns the indicating dial.

U. S. No. 2,362,344. L. D. Baver and B. T. Shaw. Iss. 11/7/44. App. 6/12/40 and 12/31/40. Assign. The Ohio State University Research Foundation.

Apparatus for Measuring Moisture. A device for determining the moisture content of materials and having in contact with the material a small heating coil connected in a Wheatstone bridge circuit and observing the resistance change when a large current is applied.

U. S. No. 2,362,372. E. S. Halfmann. Iss. 11/7/44. App. 1/23/42.

Apparatus for Measuring Alternating Current in the Conductors and/or in the Sheaths of Electric Cables. A device having a split-core transformer to measure the sum of core and sheath currents, a pair of sheath probes to measure the voltage drop in a known length of cable sheath, and a circuit to adjust the phase and measure the difference of these voltages.

U. S. No. 2,362,616. R. T. Cloud. Iss. 11/14/44. App. 10/10/42. Assign. Stanolind Oil and Gas Co.

Pendulum Compensator. An acceleration compensator for an elevation meter in which a pendulum deflection is integrated, acceleration torque on the pendulum being compensated by an electromagnetic torque produced by a coil whose current is derived from a generator on the vehicle wheel through a condenser or transformer.

U. S. No. 2,362,626. H. D. Griffin. Iss. 11/14/44. App. 4/8/43. Assign. Consolidated Vultee Aircraft Corp.

Tensiometer. A cable tensiometer in which the cable is misaligned over an elliptic spring and the deformation is detected by a filament type strain gage fastened to a slightly curved strip across the elliptic spring.

U. S. No. 2,362,832. E. H. Land. Iss. 11/14/44. App. 9/16/40. Assign. Polaroid Corp.

Remote-control Apparatus Employing Polarized Electromagnetic Radiation. A remote control system in which the angle of polarization of a light or radio wave is varied, the pick-up device having two analyzers or antennae which control a relay and motor to bring them into position of equal intensity.

U. S. No. 2,362,872. L. T. Weagle. Iss. 11/14/44. App. 3/6/43. Assign. Radio Corp. of America.

Spirit Level. A spirit level vial having a luminescent material on its under side and one or two longitudinal opaque lines between the luminescent material and the vial so that the lenticular effect of the bubble produces a distinctive effect.

U. S. No. 2,363,057. W. B. Gaylord. Iss. 11/21/44. App. 5/11/43. Assign. North American Philips Co., Inc.

Electrical Measuring Device. An electronic device for measuring potential in which the potential is interrupted, amplified, rectified and fed into a tube whose cathode resistor drop partially balances the source potential, indication being obtained from a plate ammeter.

U. S. No. 2,363,181. W. L. Howland. Iss. 11/21/44. App. 7/12/43. Assign. Lockheed Aircraft Corp.

Strain Gauge. A wire filament type electrical strain gauge having its surface covered by thin metal foil to dissipate heat.

U. S. No. 2,363,373. H. C. Warner. Iss. 11/21/44. App. 3/5/42. Assign. Westinghouse Electric & Manufacturing Co.

Shaft Vibration Pickup. Apparatus for measuring the vibration of a rotating shaft having several electrodynamic seismic vibrometers with shoes bearing against the shaft, the pickup coils being connected to one coil of a wattmeter whose other coil is energized by an a-c generator of variable phase mounted on the rotating shaft.

U. S. No. 2,364,076. S. R. Jordan. Iss. 12/5/44. App. 8/14/43.

Strain Gauge Connection. A wire filament type strain gauge in which the filament approaches the lead wire at right angles to the direction of strain so as to avoid the possibility of tearing leads loose.

U. S. No. 2,365,015. E. E. Simmons, Jr., Iss. 12/12/44. App. 2/23/40 and /1/7/42.

Fluid Pressure Gauge. A fluid pressure gauge having a filament of strain sensitive wire wound around the pressure container or around a bulb to which the pressure is transmitted and observing the change in electrical resistance of the filament.

U. S. No. 2,365,072. F. H. Hagner. Iss. 12/12/44. App. 10/20/41.

Sand Timing Instrument. A timing device in which sand flowing from one compartment to another permits a weight to unlatch and depress a plunger to actuate a well instrument.

U. S. No. 2,365,218. O. R. Rogers. Iss. 12/19/44. App. 3/27/43.

Electrical Indicating and Measuring Apparatus. A circuit for separating the translation and rotation components in vibration analysis by connecting one pick-up to one diagonal of a bridge network and another pick-up to the other diagonal, and recording across the arms which give the sum and difference voltages respectively.

U. S. No. 2,365,553. J. E. Hill. Iss. 12/19/44. App. 6/17/42. Assign. Westinghouse Electric & Manufacturing Co.

Method of Analysis with Radioactive Material. A method of analyzing for an element in a material undergoing treatment by adding a radioactive isotope of the element,

determining the relationship between radioactivity and concentration of the element and thereafter measuring the radioactivity of the material.

U. S. No. 2,365,706. G. Keinath. Iss. 12/26/44. App. 1/24/42.

Temperature Compensated Condition Responsive Measuring System. A recording resistance thermometer which is transformer coupled to an a-c bridge the output of which is applied to an amplifier driving a motor which adjusts an indicating variometer to restore null balance, and also having a compensating resistance in the bridge circuit.

U. S. No. 2,365,794. A. L. Armentrout and R. A. Werts. Iss. 12/26/44. App. 10/21/42.

Method and Apparatus Useful in Repairing Wells. A method of locating leaks in a tubing string by applying pressure to force fluid through the leak and moving a by-passed piston in the tubing, an increase in pressure indicating that the piston covers the leak.

U. S. No. 2,365,923. E. A. Wilkenson and P. T. Faxen. Iss. 12/26/44. App. 2/7/41 and 5/8/42. Assign. Svenska Aeroplan Aktiebolaget.

Pressure Gauge of the Aneroid Type for Pressure Measuring in Gas or Liquid. An aneroid pressure gauge having two or more aneroid boxes with ligaments which produce torsion of an indicating shaft and balance to eliminate radial forces on the shaft.

PUBLICATIONS RECEIVED

(The publications listed below were received since issuance of GEOPHYSICS for January, 1945, and are available for loan to the membership. Articles cited are those of particular interest to geophysicists.)

American Journal of Science, Vol. 242, No. 12 (December, 1944); Vol. 243, Nos. 1, 2 (January, February, 1945), New Haven.

Bulletin of the Academy of Sciences of the Union of Soviet Socialist Republics, Vol. VIII, Nos. 2–3, "On Incomplete Systems of Time Curves of Refracted Waves," by G. A. Gamboortsev, and "On Reciprocal Points in the Seismic Reflection Method," by G. V. Riznicenko; No. 4 "To the Theory of Seismic and Seismo-Electrical Phenomena in Humid Soils," by J. I. Frenkel, and "On a Problem of Vertical Electrical Sounding," by R. I. Turkisher. In Russian, with brief English summary. Moscow, 1944.

Economic Geology, Vol. XXXIX, No. 6 (September–October, 1944), Lancaster.

Geophysical Abstracts, 118, 119 (July–September, October–December, 1944), Washington.

"Geophysics" (Annual Review), by C. A. Heiland. Reprinted from *Mining and Metallurgy*, February, 1945.

Independent Petroleum Association of America Monthly, The, Vol. XV, Nos. 8–10 (December, 1944–February, 1945), Tulsa.

Journal of Applied Physics, Vol. 15, No. 12 (December, 1944); Vol. 16, No. 1 (January, 1945), Lancaster.

Journal of the Institute of Petroleum, Vol. 30, No. 250 "Geophysical Methods Applied to Oil Prospecting," by J. McG. Bruckshaw; No. 251 (October, November, 1944), London.

Petroleum, Vol. VII, Nos. 11, 12 (November, December, 1944), Vol. VIII, No. 1 (January, 1945), London.

Proceedings of the Cambridge Philosophical Society, Vol. 40, Part 3 (November, 1944), Cambridge.

Publicaciones del Instituto de Fisiografia y Geologia:

E-1943. *Cronica Bibliografica*, by Alfredo Castellanos and Pierina Pasotti. Rosario, Argentina, 1944.

XXII. *Punta de Flecha Osea Descubierta en el Pampeano Medio del Arroyo Saladillo (Rosario, Santa Fe)*, by Alfredo Castellanos. Rosario, 1944.

Review of Scientific Instruments, The, Vol. 15, Nos. 11, 12 (November, December, 1944), Vol. 16, No. 1 (January, 1945), Lancaster.

Revista de Ciencias, Vol. XLVI, No. 449 (September, 1944), Lima, Peru.

Russian Discoveries in the Pacific Ocean and North America in the 18th and 19th Centuries. In Russian, 220 pages. Moscow, 1944.

Terrestrial Magnetism and Atmospheric Electricity, Vol. 49, No. 4 (December, 1944), Cincinnati.

World Petroleum, Vol. 16, Nos. 1, 2 (January, February, 1945), New York.

CONTRIBUTORS

CHARLES H. DRESBACH

CHARLES H. DRESBACH received the B.S. in Mining Engineering (Petroleum Geology Option) degree from the Missouri School of Mines in 1929; an M.S. in Petroleum Engineering from the University of Pittsburgh in 1933; and the professional E.M. degree from Missouri Mines in 1939. He has been with various subsidiaries of the Gulf Oil Corporation in both geological and geophysical capacities for a total of thirteen years, including the Gulf Production Company, Gulf Research & Development Company, Mexican Gulf Oil Company and Western Gulf Oil Company. For the past three and one-half years he has been Assistant Chief Geologist and Supervisor of Geophysics for the last named company, being located in the Los Angeles office. For the previous five years from 1936 to 1941 he was at the Pittsburgh, Pa., office of the Gulf Research and Development Co. as supervisor of interpretation of the Gulf Coast section of seismograph exploration. Pre-college graduation experience added about four years general engineering and oil field work.

During his location at the Pittsburgh office he was also on the faculty of the University of Pittsburgh as Visiting Lecturer in the Oil & Gas School and taught a graduate class in structural geology for two years of that time. Foreign service includes two years as Field Geologist in Venezuela from 1930–32 with the Sinclair Exploration Company (Venezuela Petroleum Company) and a little less than two years in Mexico in 1935 and 1936 with the Mexican Gulf Oil Company and Gulf Research & Development Company as Party Chief and Geophysicist of a seismograph party. This last project was practically all conducted by mule-pack operations.

He is a member of Sigma Gamma Epsilon, Triangle Fraternity, American Association of Petroleum Geologists and the Society of Exploration Geophysicists.

PHIL P. GABY

PHIL P. GABY received the degree of B.S. in Chemistry and Mathematics from Southern Methodist University in 1931. After one year of seismograph field work for Geophysical Service, Inc., he attended the University of Texas, where he received the M.A. degree in 1933. Since that time Mr. Gaby has been employed by Geophysical Service, Inc.—as computer until 1936, as party chief until 1941,

and at present as supervisor in California. He is an active member of the American Association of Petroleum Geologists as well as the Society of Exploration Geophysicists.

Photographs and biographies of contributors to this issue not appearing above have been published previously, as follows: C. HEWITT DIX, Vol. VI; No. 4, p. 460 (Oct. 1941); C. W. HORTON, Vol. VIII; No. 3, p. 318 (July 1943); NORMAN RICKER, Vol. X; No. 1, p. 127 (Jan. 1945); H. M. EVJEN, Vol. VIII, No 2, p. 187 (April 1943); R. MAURICE TRIPP, Vol. IX; No. 3, p. 414 (July 1944).

COMMUNICATIONS AND DISCUSSIONS

Dr. W. M. Rust, Jr., 1944–45, President of the Society of Exploration Geophysicists, has prepared at the editor's request the following account of the hearings of the Federal Communications Commission which were attended by him and Dr. B. B. Weatherby.

On August 15, 1944, the Federal Communications Commission issued an order scheduling a general allocation hearing commencing September 28, 1944. On the basis of this hearing, all present frequency allocations are to be cancelled and new allocations made. In September 1943, the Radio Technical Planning Board was organized. The purpose of this Board was to study the requirements of the users of radio and to make recommendations to the Federal Communications Commission concerning such needs. Unfortunately, the geophysical industry failed to obtain representation on the Radio Technical Planning Board. As a result, they recommended only two frequencies: 37,740 and 39,820 kilocycles for geophysical service. Since these two frequencies would not be satisfactory or sufficient, testimony was introduced at the September hearing on behalf of the geophysical service. Witnesses were Mr. R. J. Schilthuis, Assistant Director of Production of the Petroleum Administration for War, Washington, D. C., Dr. Benjamin Weatherby, President of Geophysical Research Corporation, Tulsa, Oklahoma, and W. M. Rust, Jr., President of Society of Exploration Geophysicists, Houston, Texas. Mr. J. H. Wofford, radio engineer on the staff of Federal Communications Commission, Washington, D. C., appeared on behalf of the Commission, outlining the present uses of radio in geophysical service.

The witnesses appearing on behalf of the geophysical service recommended retention of the nine frequencies presently allocated to the service; that is, five frequencies from 1602 to 1702 kilocycles and four frequencies from 30,620 to 35,440 kilocycles, and the addition of five frequencies in the band from 3200 to 3400 kilocycles and a number of higher frequencies in the 75 and 170 megacycle bands. The Commission apparently was favorably impressed by the testimony introduced and it is believed that the final allocations will be satisfactory. The necessity of the present medium-frequency bands around 1700 kilocycles was stressed.

On January 15, 1945, the Commission issued a report of proposed allocations from 25,000 to 30,000,000 kilocycles. The Commission proposes to allocate a total of 22 channels in the 25 to 28 megacycle band and four channels in the 156 to 162 megacycle band. All channels are to be shared with the provisional, motion picture, relay press and relay broadcasting services. In addition to these channels formally assigned to geophysical service, a large number of channels above 1000 megacycles would be available for experimental services.

The Commission contemplates the issuance of a report on the proposed allocations below 25,000 kilocycles in the near future. It is hoped that allocations to the geophysical

service of frequencies approximating the present medium-frequency bands will be included; if not, it will be necessary to make additional representations to the Commission concerning the essentiality of these frequencies to geophysical service.

W. M. Rust, Jr.
April 10, 1945.

The following is reprinted from the February number of the *Bulletin of the American Association of Petroleum Geologists* in order to acquaint the membership of the Society of Exploration Geophysicists with the history, aims, and tentative constitution of a proposed *Geological Institute of America*. Your comment will be welcomed by the Executive Committee in guiding it in arriving at a decision on affiliation.

PROPOSED GEOLOGICAL INSTITUTE OF AMERICA

At the Annual Meeting of The American Association of Petroleum Geologists at Denver in April, 1942, Dr. Carey Croneis gave an address on "Geology in War and Peace."[1] In this address Croneis " . . . contended that the profession of Geology does not occupy as high a position in National esteem, and thus in fundamental national utility, as its potential importance warrants." To correct this condition he made " . . . several suggestions for the good of the science." The first of these was—"Organize an American Geological Association to which each geologist, each person fundamentally interested in the subject may belong, regardless of the field of specialization, or prime professional application." Three other suggestions were made, the last of which has a very close relationship to the first and is as follows—"Inaugurate and consistently maintain a unified, vigorous, and yet dignified public relations program."

This address stimulated much discussion during the next several months, which was further augmented by an address—"Geological Warfare" presented by Croneis before several of the local affiliated geological societies. There developed a desire among a number of the membership of The Association American of Petroleum Geologists and other societies to have a meeting called at which the idea of an American Geological Association could be discussed.

In response to this growing sentiment, and in line with Croneis' idea that "The American Geological Association should be sponsored by the present officers of the major geological societies," Fritz L. Aurin, then President of the AAPG, sent a letter in March 1943 to all national and local societies which had geology as their principal interest. This letter invited each society to send a representative to a meeting to be held in Fort Worth on April 10, 1943 (on the day following the close of the AAPG Annual Meeting).

Every society replied to this letter and the majority of them sent representatives. These representatives, together with many other geologists having an interest in the subject (total of more than 100) heard Croneis give a review of his ideas of the year before and outline a framework of the plan for organizing an American geological association.[2]

[1] Bull. Amer. Assoc. Petrol. Geol., Vol. 26 (July 1942), pp. 1221–49.
[2] Bull. Amer. Assoc. Petrol. Geol., Vol. 27 (July 1943), pp. 1001–07.

At this meeting A. I. Levorsen was selected as temporary chairman and after several hours of lively and constructive discussion two resolutions were adopted as follows:

"(1) Resolved that it is the consensus of this meeting that the geological organizations can contribute more effectively to the service of society by sponsoring a new association which shall have for its purpose the coordination and integration of the efforts designed to demonstrate universal applications of the earth sciences.

"(2) Resolved that the chairman of this meeting shall appoint a committee of five composed of representatives of societies here present, who shall formulate a statement of the fundamental purposes of the proposed association for the advancement of earth sciences and a suggested form of organization to accomplish these purposes, and that the statement and plan be transmitted to each of the interested societies with the request that they appoint official representatives to attend an organization meeting to be held at the call of the Chairman of this meeting at the earliest practicable date."

The following committee was named pursuant to resolution (2) above:

Lincoln R. Thiesmeyer, Chairman
A. Rodger Denison
W. B. Heroy
W. Taylor Thom, Jr.
Paul Weaver
Carey Croneis, Consultant
Paul H. Price, ex-officio
A. I. Levorsen, ex-officio

The work of this committee was summarized by Levorsen as follows:

"This committee (with the exception of Thom, Weaver, Croneis and Price, who were unable to be present but who later, by correspondence, concurred in the action taken) met for three days, August 20, 21 and 22, 1943, in Chicago. The committee, which was assisted throughout the meeting by the active participation of Fritz L. Aurin, Fred H. Lahee, Ira H. Cram and Theron Wasson, discussed the various possible ways of achieving the desired results. In general, the methods suggested were:

(1) Changing the Constitution of one of the existing societies in order to expand its activities;
(2) Organization of an entirely new society consisting of individual members, probably with requirements for membership less in geological achievement than in any of the present national organizations; and
(3) Organization of a federation, an institute, or a council in which the membership shall be in either:
    (a) the national geological organizations;
    (b) national and local geological organizations.

"The committee unanimously agreed that the best method would be a federation or council of the national earth science societies whose members have professional standing. This is somewhat along the lines by which the physicists and biologists have united their societies. The advantages of such a plan over the others are as follows:

(1) It does not require the joining of a new association, institute or society by the individual;

(2) If all the local societies were included in the governing board, when such a board met it would be a large and cumbersome group on the scale of an annual convention. By confining the membership to the national organizations, with the work done by a board of directors of not over 15 or 20 persons, a means is provided of efficiently and economically carrying out the aims of geology. The proposed organization is a working group.

(3) Most geologists, geophysicists, and engineers, who are members of local societies are also members of one or more of the national organizations and they will be represented through such membership equally as well as if the local societies were included. Other interested persons not so represented may be reached through some more general and popular publication than the present technical journals depending on the action of the governing board.

Tentative Constitution

"The result of the committee meeting in Chicago was the drawing up of a tentative constitution in accordance with the conclusions that a council or federation of geological societies was the most practical and efficient manner of handling the problem. The constitution which was drawn deliberately gives the council, through its directors, broad and flexible powers because it is not possible at this time to define the activities or actions which may at some future time best serve the interests of geology."

Levorsen was instructed by this committee to communicate the results of the committee's findings to the several geological organizations who were or might be interested in their deliberations. On April 3, 1944 Levorsen sent a report and the tentative constitution as prepared by the committee to the secretary of the following geological societies:

American Association of Petroleum Geologists
American Geophysical Union
American Institute of Mining & Metallurgical Engineers
Geological Society of America
Mineralogical Society of America
Paleontological Society
Seismological Society of America
Society of Economic Geologists
Society of Economic Paleontologists and Mineralogists
Society of Exploration Geophysicists
Society of Vertebrate Paleontologists

The following action was requested of each society to whom the report was sent:

(1) Officially study the proposed constitution and its implications to their organization;

(2) Advise of any suggestions or changes which should be made to comply with their constitution or the way in which they transact their business;

(3) Advise of the procedure which will be followed and the time required for their governing body to approve in principle, but without final commitment, the tentative constitution and to authorize an official representative to meet with the representatives of the other Founder Organizations in an exploratory constitutional convention where a final constitution may be drawn in which the interests of each organization will be considered. This proposed final constitution would then be re-submitted to each of the prospective Founder Societies for final approval.

It required considerable time for the several societies to comply with the action requested in the letter so that it was not until September 20, 1944 that a call was issued for a meeting of the official representatives of the several societies, at which the tentative constitution could be examined and rewritten to conform with the many comments and criticisms which had been made.

Sixteen official representatives of eight societies and six observers met in New York at the headquarters of the Geological Society of America on October 22 and continued their meeting into October 23. In all, a total of 22 geologists took part in the discussions during these two days. This was a "constitutional convention" and the primary business conducted at this meeting was the rewriting of the tentative document which had been submitted to these societies.

Lincoln R. Thiesmeyer, chairman of the committee appointed at Forth Worth and secretary (by election) of the meeting in New York, prepared a report and summary of the ideas of those favoring the establishment of the AMERICAN GEOLOGICAL INSTITUTE. The following information is taken from his letter of November 15, 1944:

The Needs for the Organization

1) The need for an organization which will represent authoritatively all the fields of geology and all professional workers in the multiplying specialties of geologic science and technology on problems of common interest or of public service.

2) The need to provide a simple and efficient mechanism for coordinating the efforts of existing organizations in these fields on matters of common interest. It is obvious that the service of the earth sciences to society can be immeasurably increased by such cooperative effort.

3) The need for both wider and fuller understanding among intelligent people of the meaning and especially of the usefulness of earth sciences. The most striking example of this need, one that has impressed many geolgists deeply, is the failure of our military leaders to call upon geological sciences for a greater application of their special disciplines in the present war.

After a thorough exploration of several alternative proposals for meeting these needs the representatives present voted that establishment of a federation of independent national societies, each retaining its complete autonomy while cooperating with others for their mutual benefit, holds greater promise of success than creation of a new society that would require membership by individuals, or than the modification of an existing organization. Faith in this conclusion is strengthened by the striking progress of just such federation in two of our sister sciences—the Union of American Biological Societies, founded nearly twenty-five years ago, and the American Institute of Physics, now in its fourteenth year.

Scope of the Organization

At the New York Meeting there was extensive discussion on the specific objectives and character of such an organization for the earth sciences. There was general agreement that it should have the broadest possible scope, encompassing in its objectives the entire field of pure and applied geology. It should become the means of implementing a pledge of cooperation between groups having diversified interests but a common denominator in the parent science, geology.

Obviously a list of specific objectives would reflect and might even be to some extent a composite of the objectives of the constituent organizations. The list should, however, be more comprehensive than the dominant objectives of any of the individual societies. Broadly stated, the objectives of the proposed new organization might include all those listed below:

List of Possible Objectives

To coordinate effort among all organizations, institutions, societies and agencies functioning in the field of earth sciences;

To improve and extend the application of geologic science to the development of mineral resources and to human industry and welfare;

To promote public education in geology and in its usefulness to society;

To encourage and promote research and investigation in earth sciences and in other sciences contributing to a knowledge of the earth and of its history;

To serve as a single, unifying and authoritative voice for all branches of geologic sciences in relation to government, to military circles and to the general public;

To encourage closer relations between geology and the other sciences;

To improve the education and increase and improve the supply of geologists, and other professional groups engaged through study, research, teaching or application in either pure or applied geology;

To increase and improve the supply of competent teaching personnel in all fields of earth sciences;

To become a center of information and counsel to all agencies interested in procuring the services of men trained in earth sciences.

It is thought that the degree of emphasis to be given to any one or any combination of these goals, and the specific means to be taken for achieving them, should be determined by the Institute's Board of Directors, rather than by the group at the Constitutional Convention. In this way the member organizations can control both the tenor and the tempo of the program. This control should be exercised by each organization on an equal basis, regardless of the size of its individual membership or the stature of its treasury. This is desirable because extensive overlapping of membership between our societies makes true equality of numerical representation almost impossible.

All are agreed that in attempting to carry out these purposes the new organization should utilize existing machinery wherever feasible and should seek diligently both to avoid and to eliminate duplication of effort and expenditure. This means operating to a substantial degree through the member organizations. Nevertheless the Institute should also initiate all new activities which the Board finds are for the common good.

For efficient operation it should have a simple organizational pattern and should engage competent full-time personnel to carry out the policies of its governing group. This is the only assurance of that continuity of effort, that commonly is the difference between noble intentions and real achievements.

To do this on a scale merited by the urgency of the need, consistent with the dig-

nity of the professional societies represented, and inspiring confidence both internally and in the public mind, calls for substantial financing. Therefore, the Institute must have the power to solicit and receive funds. A strong sentiment was expressed that financing of the proposed Institute should not be undertaken by the member societies through dues or commitments made as an obligation of membership, but should be procured through action of its own governing body after it has been formally created. To carry on the program for the first year or two it may be desirable to secure voluntary contributions from interested individuals or groups. There is no reason to believe, however, that its Directors will not be successful in finding the necessary funds for self support if they develop a program properly conceived, carefully controlled and appropriately represented. On the contrary, the success of the American Institute of Physics in obtaining ample funds from foundations and from industry demonstrates the possibility.

The constitution of the proposed AMERICAN GEOLOGICAL INSTITUTE is given in full below. It is the result of nearly two years of work, study and deliberation by a widely diversified group of geologists:

ARTICLE I—NAME

The name of this organization shall be the AMERICAN GEOLOGICAL INSTITUTE.

ARTICLE II—PURPOSE

The purpose of this organization is the advancement of geology in all its branches by providing an agency for the cooperation of non-profit organizations active in the fields of pure and applied geology.

ARTICLE III—MEMBERSHIP

The following organizations are eligible for initial membership in the Institute:

American Association of Petroleum Geologists
American Geophysical Union
American Institute of Mining & Metallurgical Engineers
Geological Society of America
Mineralogical Society of America
Paleontological Society
Seismological Society of America
Society of Economic Geologists
Society of Economic Paleontologists and Mineralogists
Society of Exploration Geophysicists
Society of Vertebrate Paleontology

Other non-profit organizations of national scope may be admitted to membership by the approval of two-thirds of the member organizations.

ARTICLE IV—BOARD OF DIRECTORS

The control and management of the affairs of the Institute shall be vested in a Board of Directors consisting of two directors designated by each member organization.

The Directors shall be designated for a term of two years, except that initially one Director from each member organization shall be designated for one year. In case of a vacancy the member organization concerned shall make a new designation to complete the unexpired term. For purposes of determining the terms of Directors, a year shall be construed as the period extending from the close of one annual meeting to the close of the next.

Three Directors-at-large may be chosen annually by the Board of Directors to serve for one year as additional regular members of the Board.

ARTICLE V—OFFICERS

The officers of the Institute shall be a President, a Vice-President, and a Secretary-Treasurer, who shall be elected annually by the Board of Directors from among its members. They shall take office at the close of the meeting at which they are elected. The President, or in his absence, the Vice-President, shall preside at meetings of the Board of Directors. The duties of the officers shall be those usually devolving upon such officers, except as may be determined by the Board of Directors.

ARTICLE VI—MEETINGS

The annual meeting of the Board of Directors for the election of officers and for the transaction of such other business as may properly come before the meeting shall be held in December or January at such time and place as the President may designate. Directors representing two-thirds of the member organizations shall constitute a quorum, and a majority vote of the Directors present shall be required for the transaction of business. A member organization may designate alternates for any of its Directors unable to attend.

ARTICLE VII—EXECUTIVE COMMITTEE

There shall be an Executive Committee of the Board of Directors which shall consist of the President, the Vice-President and the Secretary-Treasurer of the Institute.

The Executive Committee shall be charged with the conduct of such business as may be delegated to it by the Board of Directors and shall have authority to act for the Board in the interim between meetings of the Board to such extent as the Board may authorize.

With the prior approval of the Board of Directors, the Executive Committee may establish a headquarters office and employ qualified personnel for conducting the business of the Institute.

ARTICLE VIII—OTHER COMMITTEES

The Board of Directors shall have the power to establish other committees, appoint their members and assign their duties. The members of such committees may or may not be members of the Board. The term of each such committee, unless otherwise specified, shall expire at the close of the next annual meeting of the Board following the appointment of the committee.

ARTICLE IX—FINANCES

The Institute shall have the power to solicit and receive funds. The Board of Directors shall have control of the management and disbursement of the funds of the Institute.

ARTICLE X—AMENDMENTS

Amendments to this Constitution may be proposed in writing to the Board of Directors by any Director. Upon at least thirty days notice, they shall be considered by the Board of Directors, and, if approved, shall become effective upon ratification by two-thirds of the member organizations.

ARTICLE XI—RULES AND REGULATIONS

The Board of Directors may adopt such rules and regulations as it deems necessary or desirable for the conduct of the affairs of the Institute.

ARTICLE XII—RESIGNATION

Any member organization may resign by giving written notice to the President of its withdrawal from the Institute, and thereupon its membership and the terms of office of the Directors designated by it shall terminate.

ARTICLE XIII—RATIFICATION

This Constitution shall become effective upon its ratification by seven of the organizations listed in Article III.

In the form here presented the Constitution was approved by the representatives of eight national geological organizations. It is now referred back to each of these eight organizations for consideration by the membership and officers of these organizations. This Constitution is now before the membership and officers of The American Association of Petroleum Geologists for their consideration. Ratification by this organization and six others named in the Constitution will activate the AMERICAN GEOLOGICAL INSTITUTE.

A. Rodger Denison, Representative,
The American Association of Petroleum Geologists,
New York Meeting
January 10, 1945

THE SOCIETY ROUND TABLE

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The Executive Committee has approved for publication the names of the following candidates for membership in the Society. This publication does not constitute an election, but places the names before the membership at large. If any member has information bearing on the qualifications of these nominees, he should send it to the Secretary within thirty days. (Names of sponsors are placed beneath the name of each nominee.)

ACTIVE

Joel Otis Ayres
H. B. Peacock, E. D. Gaby, V. W. Teufel

Stewart Barclay
A. J. Hintze, W. H. Courtier, Vincent Miller

Carl Walter Blakey
G. H. Westby, T. A. Manhart, A. J. Barthelmes

Joe Randolph Bradley, Jr.
O. W. Anderson, W. A. Matthews, R. A. Weingartner

William Brison Brinnon
Paul E. Nash, W. B. Raper, J. C. Menefee

George Edgar Conover
Henry C. Cortes, Paul E. Nash, Jack W. Peters

Harold Arthur Culp
Hart Brown, C. Sheldon Sharp, L. H. Boyd

James Dennis Divelbiss
C. H. Hightower, J. P. Woods, C. G. McBurney

Albert Francis Dugan
Henry C. Cortes, Paul E. Nash, Jack W. Peters

Maurice Gordon Frey
J. W. Hoover, L. I. Brown, E. D. Gaby

Eugene William Frowe
R. Ellis Smith, J. M. Kendall, H. H. Evinger

Donald Cleland Grange
Hart Brown, L. H. Boyd, C. S. Sharp

Castle J. C. Harvey
Andrew Gilmour, John L. Ferguson, Jess Vernon

Marion Reece Henderson
T. O. Hall, G. W. Carr, P. M. Konkel

Homer Jensen
J. M. Kendall, David Sheffet, F. L. Johnson

James Eugene Kamitchis
E. V. McCollum, Wm. Schriever, Craig Ferris

Monroe W. Kriegel
Norman Ricker, P. S. Williams, E. M. McNatt

William C. Lamb
E. A. Eckhardt, Leo J. Peters, L. L. Nettleton

C. J. Lomax
E. D. Alcock, John A. Gillin, Paul Farren

John Edward McDougall
J. W. Hoover, C. Brown, E. D. Gaby
Nelson Kingsland Moody, Jr.
G. H. Westby, A. J. Barthelmes, S. W. Wilcox
Hugh Porter, Jr.
F. F. Reynolds, R. R. Rosenkrans, H. H. Happel
George Wylie Reed
G. H. Westby, A. J. Barthelmes, Stanley W. Wilcox
Chester Sappington
T. O. Hall, W. Harlan Taylor, I. M. Griffin, Jr.
Serge Alexander Scherbatskoy
G. H. Westby, Daniel Silverman, P. S. Williams
Horace Edward Shell
Frank Ittner, Cecil Reel, T. E. Dennis
John M. Sturdevant
Cecil H. Green, M. C. Kelsey, J. Frank Rollins
Gerald Homer Tefft
Edw. G. Schempf, K. A. Robertson, John C. Hoffman
Vindex Hodge Waddell
Booth B. Strange, C. J. Donnally, Fred J. Di Giulio
Raymond Oscar Wingett
E. A. Eckhardt, L. J. Peters, D. A. DeWoody
Alexander Charles Yokubiatis
L. A. Scholl, Jr., R. L. Lay, M. E. Hibbler

ASSOCIATE

John Archibald Armstrong
H. W. Brown, H. W. Buckner, C. N. Hurry
Calvin Robert Bradley
John Sloat, William A. Drennan, Dupree McGrady
Everett Lawyer Campbell
Lorenz Shock, Paul Farren, E. D. Alcock
Jerrel Washington Gaither
E. C. Livingston, M. J. Walczak, E. D. Alcock
Ernest Palmer Giles
W. Harlan Taylor, W. O. Bazhaw, T. L. Allen
Julian Hawes
Craig Ferris, E. V. McCollum, Andrew Brown
Ival Waldine Hollingsworth
W. W. Newton, T. R. Shugart, J. D. Perryman
Ivan Cecil Hovey
Roy F. Bennett, H. E. Banta, F. M. Mannestine
Harold Robert McCormack
James B. Macelwane, S. J., Lorenz Shock (III-D-1 of the Constitution)
John F. Pratt
Hart Brown, L. H. Boyd, W. H. Fenwick
Nelson John Rumsey, Jr.
W. W. Butler, L. B. Trombla, Frank Ittner

James Ivan Walton
Norman Ricker, R. S. Dahlberg, Jr., F. G. Boucher
Maurice Dennick Wickerham
W. J. Osterhoudt, John E. McGee, G. B. Lamb
Lonnie Clyde Williamson
Roy F. Bennett, H. E. Banta, F. M. Kannenstine
Sulhi Yungul
Beno Gutenberg, Hugo Benioff (III-D-1 of the Constitution)

TRANSFER TO ACTIVE STATUS

Robert Baum
Peter Dehlinger
Clinton O. Hurd
Robert W. Jones
A. J. Oden
J. H. Ransom

PERSONAL ITEMS

J. C. HEGGBLOM, of the Western Gulf Oil Co., has moved from Sacramento to Modesto, California, where his postal address is Box 973.

SAM ZIMMERMAN, Party Chief for the Carter Oil Co., may be addressed at Box 312, Kemmerer, Wyoming, where he has moved from Newcastle.

CHARLES B. AIKEN is Vice-President and Director of Research for Electro-Mechanical Research, Inc., 2712 Leeland Ave., Houston 3, Texas.

R. F. ALDREDGE is in foreign service with the Seismograph Service Corp. of Delaware, Aptdo. Aereo 4000, Bogota, Colombia, S. A.

H. E. ITTEN is Party Chief for the Stanolind Oil and Gas Co., P. O. Box 961, Corsicana, Texas.

DONALD BEETH, of the Continental Oil Co., has been transferred from Ponca City, Oklahoma, to Houston, Texas, where company offices are located at 612 Oil and Gas Bldg.

E. C. LIVINGSTON, formerly of the National Geophysical Co., is now with the Geophysical Section of the Atlantic Refg. Co., Box 2819, Dallas, Texas.

CHARLES A. SWARTZ has left the Gulf. Res. and Dev. Co. to accept employment with the Union Oil Co. of California, 1134 Commerce Bldg., Houston, Texas.

R. F. (STORMY) COOKE, formerly with Geophysical Service, Inc., is now Party Chief with the Garrett Exploration Co. He may be addressed at P. O. Box 267, Jacksboro, Texas.

J. P. WOODS, until recently Research Associate at Harvard, is with the Atlantic Refg. Co. of Dallas, Texas. His address in that city is 3629 Cragmont.

C. H. HIGHTOWER, also with Atlantic, has been transferred from Houston to 706 Magnolia Bldg., Dallas 1, Texas.

LAVON C. DODD, Design Engineer with the Lockheed Aircraft Corp., is located at 1356 Grandview Ave., Glendale, Calif.

E. I. GRIZZELL and M. M. HART, both of the Independent Exploration Co., are on overseas duty, with their postal address c/o Puccini, Aptdo. Postal No. 844 (Aptdo. Aereo 342), Barranquilla, Colombia, S. A. W. H. MORGAN, of the same company, may be addressed in care of Thos. F. Roche, Aptdo. Postal No. 323, Barranquilla, Colombia, S. A.

ROBERT S. LAMON, District Geologist for the Richmond Pet. Co. of Colombia, has been transferred to the Richmond Exploration Co., Aptdo. 93, Maracaibo, Venezuela, S. A.

LT. C. C. LUDWICK, formerly with Shell, is located at 4001 Empedrado, Tampa 6, Florida.

ROBERT J. MCGANN, of the Western Geophysical Co., is currently located at Vernal, Utah.

W. WISE HOLLINGSWORTH left the employ of the Independent Exploration Co. in December, 1944. He is now contracting geomagnetic surveys, in association with H. F. VINSON and M. L. SUGGS, and is located at 401 Washington Ave., Shreveport, La.

C. MAYNARD BOOS, who has served as an Industrial Analyst with the War Production Board in Washington, D. C., for the past several years, has returned to Denver, Colorado, as geologist for the Barnsdall Oil Co. His home address is 2036 S. Columbine St.

CAPT. RALPH D. LYNN is with Hq., 2nd Army Art'y. Sec., c/o Postmaster, Memphis, Tenn.

WILLIS A. SEYFERT, Assistant District Manager of E. I. duPont de Nemours and Co.'s Explosives Divisions, has returned to Joplin, Mo., from Dallas, Texas. He is again located at 816 Joplin National Bank Bldg.

GEORGE D. MITCHELL, JR., and JAMES L. SAULS, JR., have resigned from the Texas Co. to form the Advanced Exploration Co., with offices at 622 First National Bank Bldg., Houston 2, Texas.

W. C. CLARK, formerly with the Continental Oil Co., in the Rocky Mountain Area, has joined the Independent Exploration Co., 901 Esperson Bldg., Houston 2, Texas, as Party Chief.

C. M. ENGLAND, of the Stanolind Oil and Gas Co., may be addressed at General Delivery, Haskell, Texas.

J. G. FERGUSON is Gravity Supervisor for the Western Geophysical Co. His current mailing address is Box 596, Natchez, Miss.

J. P. GARNER, Party Chief for the Texas Co., has offices at 811 Broadway Tower Bldg., Enid, Okla.

ROBERT C. HANNUM, formerly with the Stanolind Oil and Gas Co., is an Officer Candidate with the 9th Co., 3rd STR, Class 436 Inf. OCS, Ft. Benning, Ga.

ROE W. CARSO, formerly Gravity Party Chief with the Continental Oil Co., has accepted a position as Research Computer in the Seismic Dept. of the Sun Oil Co., Beaumont, Texas.

TUN YIN CHANG is now Chief Computer for the Atlantic Refg. Co., Geop. Section, P. O. Box 2819, Dallas, Texas.

LAURENCE N. DEXTER, also formerly with the National Geophysical Co. is Party Chief for Atlantic. His present mailing address is P. O. Box 275, Three Rivers, Texas.

WALTER E. JASPER is Asst. Seismologist with the Shell Oil Co., Inc. He is presently located in Ruston, La., with the postal address Box 504.

PHILLIP J. KEMPSKY, Party Chief for the Amerada Pet. Corp., is located at 552 Subway Terminal Bldg., Los Angeles 13, Calif.

G. J. KOHLER, JR., Party Chief for GSI, should be addressed as follows: Depto. de Exploracion, Aptdo. 86, Coatzacoalcos, V. C., Mexico.

JOHN M. KENDALL has requested a change of address to P. O. Box 77, Virginia, Minn.

C. RUSSELL HALE is Junior Observer for the United Geophysical Co., 595 East Colorado St., Pasadena 1, Calif.

JOHN F. ANDERSON, formerly with Sun, is now associated with the Geophysical Engineering Co., 410 Beacon Bldg., Tulsa, Okla., as Seismograph Supervisor.

LEWIS MIMS, Chief Radio Technician, is stationed at the U. S. Coast Guard Operating Base, Mobile, Alabama, having been transferred there from New Orleans, La.

PAUL FARREN, Supervisor for the National Geophysical Co., Inc., is located at 3308 Moore Drive, Texarkana, Texas.

LT. COL. JOHN V. LONG should be addressed at Hq. 93rd IAT B, Camp Maxey, Texas.

MAURICE SKLAR, of the Shell Oil Co., Inc., has been transferred from Rosenberg, Texas, to Hammond, La., where his postal address is Box 1071.

HERBERT J. FERBER, of the Western Gulf Oil Co., has been transferred from Bakersfield to Modesto, Calif., the postal address being Box 973.

R. D. ARNETT, P. J. CLINE, C. G. MCBURNEY, J. H. PERNELL, C. C. WILLIAMS, and RICHARD WILLIAMS are partners in the newly-formed Seismic Engineering Company of Dallas, Texas. Offices are in the Kirby Bldg. in that city. The partners were until recently associated in the National Geophysical Company, also of Dallas, and recently reorganized into the National Geophysical Co., Inc., and the National Geophysical Drilling Co.

HAROLD H. PENTZ is no longer associated with C. H. Frost Gravimetric Surveys of Tulsa, Okla. He may be addressed currently in care of General Delivery, Vernal, Utah.

JAMES A. LONG is Seismic Party Chief with the Stanolind Oil and Gas Co., Box 267, Picayune, Miss.

CLARE N. HURRY, of the Carter Oil Co., has headquarters in Shreveport, La., with the mailing address P. O. Drawer 1739, Shreveport.

WILLIAM E. B. PAPPERT is with the Richmond Exploration Co., Aptdo. 93, Maracaibo, Venezuela, S. A.

RUSSELL E. SHAFER, for the past few years a Captain in the Signal Corps, has rejoined the Sun Oil Co., P. O. Box 2831, Beaumont, Texas, as Seismograph Party Chief.

L. F. FISCHER has resigned from the Atlantic Refining Co. to accept a position as Division Geophysicist with the Sohio Petroleum Co., P. O. Box 145, Shreveport, La.

ENSIGN ALLEN M. RUGG, JR., may be addressed in care of Mrs. Rugg at 3241 W. 22nd Ave., Denver, Colo.

ROBERT W. JONES, Operator for the Gulf Res. and Dev. Co., has the postal address Box 838, Lovington, N. M.

C. R. LOWE is Party Chief for the Independent Exploration Co., 901 Esperson Bldg., Houston 2, Texas.

The Atlas Exploration Company is successor to the Mott-Smith Corporation. The address—1041 Mellie Esperson Bldg., Houston 2, Texas—remains the same. JOHN HARRIS has been advanced to the status of Field Supervisor for the new concern.

J. T. RANDELL, who has been serving as Geologist for the Demerrara Bauxite Co. Ltd. of Mackenzie, B. G., has advised the Society that he is returning to Canada. He should be addressed c/o Mr. H. Plomp. 109 Glebeholme Ave., Toronto, Ontario, Canada.

L. W. SAUNDERS, until recently a Consulting Geologist, is Vice-President of the Independent Exploration Co. of Calif., with offices at 531 California Ave., Bakersfield, Calif.

SAMUEL R. MARSH, Seismograph Party Chief for the Carter Oil Co., is located at Forest, Miss., where his postal address is Box 329.

JOHN E. PALMER, formerly with Humble, is Gravity Meter Operator for the Carter Oil Co., Box 801, Tulsa 2, Okla.

J. A. PEOPLES, JR., has left the Sperry Gyroscope Co. to accept a position as Assistant to the Project Director of the Woods Hole Oceanographic Institution, Woods Hole, Mass. The success in submarine photography of MAURICE EWING, Associate in Submarine Geology at the Institution, has recently received widespread notice in the nation's press.

GEORGE B. SOMERS, who has served as a Technician in the U. S. Naval Bureau of Ordnance for the past several years, has returned to geophysical work as Seismic Party Chief for the General Geophysical Co. His home address is 4380 Wheeler Ave., Houston, Texas.

ELLIOTT SWEET has been returned to inactive duty by the U. S. Navy Dept. His present address is that of the Sweet Geophysical Co., of which he is President—21544 Rambla Vista Drive, Pacific Palisades, Calif.

W. J. PFEFFER is Gravity Meter Party Chief in the Exploration Dept., Creole Pet. Corp., Aptdo. 889, Caracas, Venezuela, S. A.

Following a leave of absence of several years, during which he served in the Naval Ordnance Laboratory in Washington, D. C., WHITMAN D. MOUNCE has returned to the Humble Oil and Refg. Co., 256 Humble Bldg., Houston, Texas, as Research Geophysicist.

WAYNARD B. PERRY is Party Chief for the Carr Geophysical Co., 1334 Commerce Bldg., Houston 2, Texas, having left the Seismograph Service Corp. to accept the new position under G. W. CARR, owner of the firm.

V. E. CHILD, of the Texas Co., has moved from Craig, Colo., to Crockett, Texas, where his mailing address is Box 877.

MERLE C. BOWSKY has been advanced to the rank of Major in the Signal Corp, APO 655, c/o Postmaster, New York, N. Y., according to advice recently received from Mrs. Bowsky.

L. B. TROMBLA is Seismograph Supervisor for the Superior Oil Co., 2211 Apco Tower, Oklahoma City, Okla.

D. F. SMITH, formerly with SSC, has been with the Atlantic Refining Co. since last June as a geologist in the Shawnee, Okla., office. He may be addressed at 807 N. Louisa St., Shawnee.

WILLIS H. FENWICK is serving as Divisional Manager for the Brown Geophysical Co. in Casper, Wyoming. His postal address is Box 319.

C. B. SMITH is with the Atlantic Refg. Co., 1001 City Bank Bldg., Shreveport, La.

CECIL E. REEL recently left the United Geophysical Co. to accept a position as Seismologist with the Superior Oil Co. of Calif. His address is 2605 Avenida Escuela, Bakersfield, Calif.

MALCOLM S. MORRISON has entered foreign service, and should henceforth be addressed in care of the Mene Grande Oil Co., Aptdo. 709, Caracas, Venezuela, S. A.

E. L. MOUNT is Party Chief for the Continental Oil Co., Ponca City, Okla.

GLENN M. CONKLIN has resigned from SSC to accept a position as Seismic Interpreter with the Sun Oil Co., in Beaumont, Texas. His home address is 2605 Amarillo in that city.

R. R. MOORE, Computer for Geophysical Service, Inc., is now in foreign service. He may be addressed at Norte 4, #15, Orizoba, Ver., Mexico.

LT. (j.g.) E. B. STOVER, JR., should be addressed at Cub. 17, ABATU, Lido Beach, Long Island, New York.

M. D. TUCKER, Seismograph Party Chief for the Stanolind Oil and Gas Co., has been transferred from Ozona to Sonora, Texas, where his postal address is Box 5294.

S 1/C D. E. WARD is located at RMS, Co. 68, Bks. 20, Treasure Island, San Francisco, Calif.

W. C. BONEBRAKE is Party Chief of the Atlantic Refg. Co.'s Party #15. Box number for the home address is P. O. Box 2819, Dallas, Texas.

J. M. BUGBEE, Senior Exploitation Engineer with Shell Oil Co., Inc., has moved from Houston, Texas, to Lake Charles, La. He will serve as Louisiana Division Subsurface Engineer in his new location.

MICHAEL ALLON, of the Gulf Res. and Dev. Co., has as his new address Box 838, Lovington, N. M.

JOHN L. BIBLE, formerly with the Stanolind Oil & Gas Company, has resigned to become Executive Vice-President and Treasurer of the North American Geophysical Company, with offices at 636 Bankers Mortgage Building, Houston 2, Texas. He will supervise gravity surveys for North American, while HUGH C. SCHAEFFER, formerly with the United Geophysical Company, will supervise seismic surveys. REGINALD C. SWEET has charge of the Company laboratory.

ELMER K. BOLTON, Chemical Director of E. I. du Pont de Neumours & Company, has been awarded the Perkin Medal of the Society of Chemical Industry for his work in the development of neoprene and nylon. Another recent news release issued by du Pont notes that nylon-insulated wires and rubber plug closures will henceforth be used in all electrical blasting caps produced by the company.

A review of geophysical exploration in 1944, prepared by C. A. HEILAND, appeared in the February, 1945, issue of *Mining and Metallurgy*. A reprint of this article is available for loan at Society headquarters.

JOSEPH A. SHARPE has submitted his resignation as Chief Physicist of the Stanolind Oil & Gas Company in order to become affiliated with C. H. Frost Gravimetric Surveys, Inc., as Vice-President. Dr. Sharpe will be located at 1242 S. Boston, in Tulsa.

THE SOCIETY OF EXPLORATION GEOPHYSICISTS
CONSTITUTION AND BY-LAWS

(As amended to April, 1943)

I. Name

This Association shall be called the "Society of Exploration Geophysicists."

II. Object

The object of this Association is to promote the science of geophysics especially as it applies to exploration.

III. Membership

A—Members

1. Any geophysicist of recognized standing shall be eligible to membership, whether or not he is engaged in petroleum geophysics or in geophysical prospecting.
2. Any physicist, mathematician, geologist, or engineer of recognized standing who is investigating a geophysical problem or problems shall be eligible to membership.
3. Any geologist of recognized standing who is not a geophysicist of recognized standing, but who is acting as chief, or division chief in charge of geophysical surveying, shall be eligible to membership.

B—Associates

1. Any geophysicist, geologist, engineer, mathematician, or physicist who is a graduate of an institution of recognized scientific standing who is engaged in geophysics and who is not eligible to membership shall be eligible to associate membership.
2. Any person who is not a graduate of an institution of recognized scientific standing and who is not eligible to membership and who has shown ability in a routine phase of geophysical work and who is in a position of responsibility in geophysical surveying shall be eligible to associate membership.
3. Any representative or employee of a firm or corporation engaged in supplying equipment or supplies to the geophysical prospecting industry, provided such individual is the graduate of an institution of recognized scientific standing, or provided otherwise that such individual is qualified by adequate technical experience, shall be eligible to associate membership.
4. Associate members shall be known as associates.
5. Associates shall enjoy all the privileges of membership in the Society, save that they shall not hold office, sign applications for membership, or vote; neither shall they have the privilege of advertising their affiliation with the Society in professional cards or professional reports or otherwise.
6. The Executive Committee may advance to active membership, without the formality of application for such change, those associates who have, subsequent to election, fulfilled the requirements for active membership.

C—Student Members

1. Any graduate or undergraduate student in residence at a recognized university or college shall be eligible for student membership.

2. Student membership shall terminate one year after a student member ceases to be enrolled at a recognized university or college.
3. The privileges of student members shall be the same as those of associate members.

D—Election to Membership

1. Every candidate for admission as a member or associate shall submit a formal application on an application form authorized by the Executive Committee, signed by him, and endorsed by not less than three members who are in good standing, stating his training and experience and such other facts as the Executive Committee shall from time to time prescribe. Provided the Executive Committee, after due consideration, shall judge that the applicant's qualifications meet the requirements of the Constitution, they shall cause to be published in an appropriate publication the applicant's name and the names of his sponsors. If, after at least thirty days have elapsed since such publication, no reason is presented why the applicant should not be admitted, he shall be deemed eligible to membership or to associate membership, as the case may be, and shall be notified of his election. Provided the Executive Committee may accept applicants for either class of membership, who, because of their geographical location or because of their lack of acquaintance with active members of this Society, are unable to secure qualified sponsors, but who otherwise are eligible for membership. Applicants for student membership may be accepted as student members upon recommendation of a faculty member of the school they are attending, and with the unanimous approval of the Executive Committee.
2. An applicant for membership, on being notified of his election in writing, shall pay full membership dues for the current year and on making such payment shall be entitled to receive the regular Society publications for that year. Unless payment of dues is made within thirty (30) days by those living within the continental United States and within ninety (90) days by those living elsewhere, after notice has been mailed of his election, the Executive Committee may rescind the election of the applicant. Upon payment of dues, each applicant for membership shall be furnished with a membership card for the current year and until such written notice and card are received, he shall in no way be considered a member of the Society.

E—Honorary Members

1. The Executive Committee may from time to time and by unanimous action elect as honorary members persons who have contributed distinguished service to the cause of geophysics. Honorary members shall not be required to pay dues.

F—Code of Ethics

1. Membership of any class shall be contingent upon conformance with the established principles of professional ethics.

IV

A—Resignation—Suspension—Expulsion

1. Any member or associate may resign from the Society at any time. Such resignation shall be in writing and shall be accepted by the Executive Committee,

subject to the payment of all outstanding dues and obligations of the resigning member or associate.

2. Any member or associate who is more than one year delinquent (in arrears) in payment of dues shall be suspended from the Society. Any delinquent or suspended member or associate, at his own option, may request in writing that he be dropped from the Society and such request shall be granted by the Executive Committee. Any member or associate more than two years in arrears shall be dropped from the Society. The time of payment of delinquent dues for either one year or two years may be extended by unanimous vote of the Executive Committee.
3. Any member or associate who resigns or who is dropped under the provisions of Sections 1 and 2 of this article ceases to have any rights in the Society and ceases to incur further indebtedness to the Society.
4. Any person who has ceased to be a member or associate under Section 1 or Section 2 of this article may be re-instated by unanimous vote of the Executive Committee subject to the payment of any outstanding dues and obligations which were incurred prior to the date when he ceased to be a member or associate of the Society.
5. Any member or associate who, after being granted a hearing by the Executive Committee, shall be found guilty of a violation of the code of ethics of this Society or shall be found guilty of a violation of the established principles of professional ethics or shall be found guilty of having made a false or misleading statement in his application for membership in the Society, shall be asked to resign from the Society by unanimous vote of the Executive Committee. The decision of the Executive Committee in all matters pertaining to the interpretation and execution of the provisions of this section shall be final.

V. Officers and Their Duties

A—Officers

1. The officers of the Society shall be a President, a Vice-President, a Secretary-Treasurer, and an Editor. These, together with the Past President, shall constitute the Executive Committee and managers of the Society. Officers shall be elected for a term of one year with the exception of the Editor, who shall be elected for a term of two years.
2. A ticket of nominations for officers and representatives shall be prepared by a Committee on Nominations which shall consist of the President and the two qualified Past Presidents in order of precedence. Favorable action of this Committee shall be two out of three votes. This Committee shall nominate two candidates for President, one of whom shall be the retiring Vice-President, and two candidates for each of the other offices to be filled.

   The ticket prepared by the Nominating Committee, as well as any other ticket presented in writing and signed by at least twenty members in good standing, shall be submitted to the President by November 30. The President shall secure written acceptance of nominations from each candidate. The names of nominees shall be placed on the official ballot which shall be mailed to each member not later than December 15. Names of candidates shall be listed alphabetically except that the name of the retiring Vice-President shall occupy

first place on the ticket. Blank spaces shall be provided on the ballot for writing in nominations for each office.

Each member shall cast one vote for each officer to be elected and shall return his ballot to the Secretary-Treasurer. Ballots to be valid must be enclosed in an envelope carrying on the outside the written signature of the member submitting the ballot, and must be received by the Secretary-Treasurer at his officially recognized address not later than ten days prior to the Annual Meeting. Only ballots received from members in good standing as of a date ten days prior to the Annual Meeting shall be valid. The Secretary-Treasurer shall indicate which ballots are valid by initialing the enclosing envelope and shall deliver the ballots unopened to the Nominating Committee for counting.

The Nominating Committee shall count the ballots immediately before the Annual Business Meeting. The candidate receiving the greatest number of valid votes cast for an office shall be declared elected to that office. In case of a tie, the Nominating Committee shall decide by a secret vote which of the candidates tied shall be elected.

The announcement of the election shall be made as the first of the new business considered at the Annual Meeting.

3. No one shall hold the office of President for two consecutive years and no one shall hold any other office for more than two consecutive years except that of Editor.

B—Duties of Officers

1. The President shall be the presiding officer at all the meetings of the Society, shall take cognizance of the acts of the Society and of its officers, shall appoint such committees as are required for the purposes of the Society, and shall delegate members to represent the Society. He may, at his option, serve on, and may be chairman of, any committee.
2. The Vice-President shall assume the office of President in case of a vacancy from any cause in that office and shall assume the duties of President in case of the absence or diability of the latter. He shall also act as Chairman of the Program and Arrangements Committee of the Society.
3. The Secretary-Treasurer shall assume the duties of the President in case of the absence of both the President and Vice-President. He shall have charge of the financial affairs of the Society and shall annually submit reports as Secretary-Treasurer covering the fiscal year, which he shall arrange to have published in the next regular issue of the recognized organ of the Society. He shall receive all funds of the Society and, under the direction of the Executive Committee, shall disburse all funds of the Society. He shall cause an audit to be prepared annually by a public accountant at the expense of the Society. He shall give a bond, and shall cause to be bonded, all employees to whom authority may be delegated to handle Society funds. The amount of such bonds shall be set by the Executive Committee and the expense shall be borne by the Society. The funds of the Society shall be disbursed by check as authorized by the Executive Committee.
4. The Editor shall be in charge of the editorial business, shall submit an annual report of such business, shall have authority to solicit papers and material for the regular Society publication and for special publications, and may accept

or reject material offered for publication. He may appoint associate, regional, and special editors.

5. In the event of absence, disability or resignation of any member of the Executive Committee, the vacant place in the Committee shall be automatically filled by the next preceding qualified Past President who shall be known as Prior Past President.
6. The officers shall assume the duties of their respective offices immediately after the Annual Meeting following their election.

VI. Executive Committee—Meetings and Duties

A—Executive Committee

1. The Executive Committee shall consist of the President, Past President, Vice-President, Secretary-Treasurer, and Editor.

B—Meetings and Duties

1. The Executive Committee shall meet preceding the annual meeting and at the call of the President may hold meetings when and where thought advisable, to conduct the affairs of the Society. A joint meeting of the outgoing and incoming Executive Committees shall be held immediately after the close of the annual Society business meeting. Members of the Executive Committee may vote by proxy, mail or person on all matters which call for favorable or unanimous action.
2. The Executive Committee shall consider all nominations for membership and pass on the qualifications of the applicants, shall have control and management of the affairs and funds of the Society, shall determine the manner of publication, and shall designate the place of the annual meeting. They are empowered to establish a business headquarters for the Society, and to employ such persons as are needed to conduct the business of the Society. They are empowered to make investments of both general and special funds of the Society. Trust funds may be created giving to the trustees appointed for such purposes such discretion as to investments as seems desirable to the Executive Committee to accomplish any of its objects and purposes, but no such trust funds shall be created unless they are revocable upon ninety (90) days' notice. Favorable action shall consist of a favoring three out of five votes. Committee members may vote by person, proxy or in writing.

VII

A—Meetings

1. The Society shall hold at least one stated meeting each year, which shall be the annual meeting. This meeting shall be held at a time and place designated by the Executive Committee. At this meeting the proceedings of the preceding meeting shall be read, Society business shall be transacted, scientific papers shall be read and discussed, and results announced by the mail ballot for officers for the ensuing year.

VIII

A—Amendments

1. Amendments to this Constitution may be proposed by a resolution of the Executive Committee, by a Constitutional Committee appointed by the President,

or in writing by any ten members of the Society. All such resolutions or proposals must be submitted at the annual meeting of the Business Committee of the Society as provided in the By-Laws, and only the Business Committee shall make recommendations concerning proposed constitutional changes at the annual Society business meeting. If such recommendations by the Business Committee shall be favorably acted on at the annual Society business meeting, the Secretary-Treasurer shall arrange for a ballot of the membership by mail within thirty (30) days after said annual Society business meeting, and a majority vote of the ballots received within ninety (90) days of their mailing shall be sufficient to amend. The legality of all amendments must be determined by the Executive Committee prior to balloting.

B—Parliamentary Regulations

1. The rules contained in "Robert's Rules of Order, Revised" shall govern the Society in all cases to which they are applicable, and in which they are not inconsistent with the By-Laws or the special rules of order of this Society.

BY-LAWS

I

A—Dues

1. The fiscal year of the Society shall correspond with the calendar year.
2. The annual dues of members of the Society shall be five dollars ($5.00). The annual dues of associates for not to exceed six years after election shall be four dollars ($4.00); thereafter, the annual dues of such associates shall be five dollars ($5.00). The annual dues of student members shall be three dollars ($3.00). The annual dues are payable in advance on the first day of each calendar year. A bill shall be mailed to each member, associate, and student member before January first of each year, stating the amount of the annual dues and the penalty and conditions for default in payment. Members, associates, or student members who shall fail to pay their annual dues by March fifteenth shall not receive further copies of the regular Society publication, shall not be eligible to vote, nor shall they be privileged to buy Society special publications at prices made to the membership, until such arrears are met.

II

A—Publications

1. The proceedings of the annual meeting, the Constitution and By-Laws, and the papers presented at such meeting shall be published at the discretion of the Executive Committee in the regular publication or in such other form as the Executive Committee may decide best meets the needs of the membership of the Society.
2. The payment of annual dues for any fiscal year entitles the member or associate to receive without further charge the regular publication of the Society for that year. $3.00 ($3.50 foreign) of the annual dues is set aside for payment of the annual subscription to the Society Journal, GEOPHYSICS.
3. The Executive Committee may authorize the printing of special publications to be financed by the Society from its general, publication or special funds and

offered for sale to members and associates in good standing at not less than the cost of publication and distribution.

4. The Executive Committee may authorize the awarding of suitable prices for the best papers submitted for publication in GEOPHYSICS under conditions designated by it.

III

A—Regional Sections, Technical Divisions, and Affiliated Societies

1. Regional sections of the Society may be established provided the members of such sections are members of the Society and shall perfect an organization and make application to the Executive Committee. The Executive Committee shall submit the application for action first by the Business Committee and second to the Society for a letter ballot as for a constitutional amemdment, and provided that the Society may revoke the charter of any regional section by similar action.
2. The Executive Committee may arrange for the affiliation with the Society of duly organized groups or societies, which by object, aims, constitution, by-laws, or practice are developing the study of geophysics or petroleum technology. In like manner, the Executive Committee may arrange conditions for dissolution of such affiliations. Affiliation with the Society need not prevent affiliation with other scientific societies. Members of affiliated societies who are not members of the Society, shall not have the privilege of advertising their affiliation with the Society on professional cards or otherwise, but shall be entitled to receive the regular publication of the Society upon payment of a fee equivalent to that charged an associate member.

IV

A—District Representatives

1. The Executive Committee may cause to be elected district representatives from districts which it shall define by a local geographic grouping of the membership. Such districts shall be redesignated and redefined by the Executive Committee as often as seems advisable. Each district shall be entitled to one representative for each seventy-five members, but this shall not deprive any designated district of at least one representative. The representatives so apportioned shall be chosen from the membership of the district by a written ballot arranged by the Executive Committee. They shall hold office for two years, their term of office expiring at the close of the annual meeting. In so far as possible, these two-year terms shall be overlapping.

V

A—Business Committee

1. The Business Committee shall be a standing committee of the Society to act as a council and advisory board to the Executive Committee and the Society. This Committee shall consist of the Executive Committee, the Prior Past President, and the district representatives. Favorable action by the Business Committee shall consist of a favorable two-thirds vote. The Secretary-Treasurer shall act as Secretary of the business meeting. Members of this Committee may vote in person, by proxy, or in writing. The Business Committee shall meet the day before

the annual meeting at which time proposed changes in the Constitution or By-Laws may be considered, all old and new business shall be discussed, and recommendations may be voted for presentation at the annual meeting.

VI

A—Amendments

1. These By-Laws may be amended by favorable vote of the Business Committee, providing that such changes have been recommended and legality approved by the Executive Committee. Such amendments shall be published in the next regular number of the recognized organ of the Society.

SOCIETY OF EXPLORATION GEOPHYSICISTS
MEMBERSHIP LIST (APRIL, 1945)

Members are urged to report to the Business Manager at P. O. Box 410, El Dorado, Arkansas, any inaccuracies in the following list, which was compiled from the most recent information at hand.

*Acheson, C. H. (Gravity Meter and Magnetometer Party Chief), c/o Imperial Oil Co., 301 Examiner Bldg., Calgary, Alberta, Canada.
Acheson, Volney A. (Jr. Geophysicist, Carter Oil Co.), 1721 E. 37th St., Tulsa 5, Okla.
Adams, Hal R. (Party Chief, Geotechnical Corp.), 1702 Tower Pet. Bldg., Dallas 1, Tex.
Adams, John A. (Party Chief, Western Geophysical Co.), 711 Edison Bldg., Los Angeles 13, Calif.
*Adams, Robert W. (Lt., U.S.N.R.), P. O. Box 664, Reseda, Calif.
Aderman, C. V. (Party Chief, Keystone Exploration Co.), 2813 Westheimer Rd., Houston, Tex.
Adler, Joseph L. (Eastern & Foreign Mgr., Independent Exploration Co.), 901 Esperson Bldg., Houston 2, Tex.
Affleck, James (Geomagnetic Interpretation, Gulf Res. and Dev. Co.), P. O. Drawer 2038, Pittsburgh 30, Pa.
*Agee, F. H. (Seis. Party Chief, National Geophysical Co.), 123 S. Greenwood St., Lebanon, Tenn.
Agnich, Fred J. (Party Chief, Geophysical Service, Inc.), 1311 Republic Bank Bldg., Dallas, Tex.
Agocs, William B. (Chief Geophysicist), Venezuelan Atlantic Refg. Co., Aptdo. 893. Caracas, Venezuela, S. A.
Aiken, Charles B. (Vice-Pres. & Dir. of Research, Electro-Mechanical Research, Inc.) 2712 Leeland Ave., Houston 3, Tex.
Alber, John L. (Operator), Geop. Dept., International Pet. Co., Negritos via Talara, Peru, S. A.
Albertson, Dorothy E. (Ass't. Computer, Texas Company), 823 S. Palace Ave., Tyler, Tex.
Albright, E. G. (M/Sgt/T, U. S. Army), A.P.O. 314, c/o Postmaster, New York, N. Y.
Alcock, E. D. (Geophysicist, National Geophysical Co.), 3412 Caruth Blvd., Dallas 5, Tex.
Aldredge, R. F. (Geophysicist), Seismograph Service Corp. of Dela, Aptdo. Aereo 4000, Bogota, Colombia, S. A.
Allen, Frank T. (Seismic Interpreter), c/o Mene Grande Oil Co., C. A., Aptdo. 45, Barcelona, Venezuela, S. A.
Allen, Lynn D. (Seismic Computer), c/o Socony-Vacuum Oil Co., C.A., Aptdo. 246, Caracas, Venezuela, S. A.
Allen, Thomas L. (Geophysicist, Petty Geophysical Eng. Co.), Box 2061, San Antonio, Tex.
Allon, Michael (Geophysicist), c/o Gulf Res. & Dev. Co., Box 838, Lovington, N. M.
Alvarez, Manuel, Jr. (Consultant, Petroleos Mexicanos), Nogal 52, Mexico City, D. F.
Anderson, John F. (Seis Supervisor, Geophysical Engineering Co.), 410 Beacon Bldg., Tulsa, Okla.
Anderson, O. W. (Party Chief), c/o Stanolind Oil & Gas Co., Box 3092, Houston, Tex.
Arick, M. B. (Capt., U. S. Army Air Corps), 211 North A St., Midland, Tex.
Arnett, R. D. (Partner, Seismic Engineering Co.), 6622 Robin Road, Dallas 5, Tex.
Arnold, Kingsland (Gravity Computer, Magnolia Pet. Co.), P. O. Box 900, Dallas 1, Tex.
Arthur, Marion A. (Engr., Office of Scientific Res. & Dev.), Johns Hopkins Univ. Physics Lab., 8621 Georgia Ave., Silver Spring, Md.
Athy, L. F. (Chief Geophysicist), Geophysical Dept., Continental Oil Co., Ponca City, Okla.
Augenthaler, R. L. (Geophysicist), California Standard Co., Lancaster Bldg., Calgary, Alberta, Canada.

* Associate Member † Student Member ‡Honorary Member

Augustat, George (Seis. Party Chief, Geophysical Service, Inc.), 1311 Republic Bank Bldg., Dallas 1, Tex.
Aurand, Harry A. (Consulting Geologist and Geophysicist), 1350 Bellaire St., Denver 7, Colo.
Autrey, D. W. (Observer, Geotechnical Corp.), 1702 Tower Pet. Bldg., Dallas 1, Tex.

Backman, John E. (Party Mgr., Gulf Res. & Dev. Co.), P. O. Drawer 2038, Pittsburgh 30, Pa.
Bader, Glenn E. (Chief Seismic Computer), Humble Oil & Refg. Co., 802 Humble Bldg., Houston, Tex.
Bailey, Lothrop H. (Asst. Geophysicist, Gulf Res. & Dev. Co.), P. O. Drawer 2038, Pittsburgh 30, Pa.
Baird, John, Rand Hall, Cornell Univ., Ithaca, N. Y.
Baird, Walter D. (Party Chief, Geophysical Service, Inc.), 1311 Republic Bank Bldg., Dallas 1, Tex.
Baker, Malcolm C. (Computer, Humble Oil & Refg. Co.), 202 Humble Bldg., Houston 1, Tex.
*Ballard, James A. (Lt., U. S. Army Air Corps), 507 Ratan Ave., LaJunta, Colo.
Banta, H. E. (Research Physicist, Independent Exploration Co.), Box 6007, Houston 6, Tex.
Banta, N. H. (Party Chief, Independent Exploration Co.), 901 Esperson Bldg., Houston 2, Tex.
Barbisch, J. B. (Seismologist, Petty Geophysical Eng. Co.), Box 2061, San Antonio, Tex.
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Dennis, Terence E.
Ellsworth, T. P.
Hale, Francis A.
Ittner, Frank
Junger, Arne
Kiesler, Ernest A.
LeConte, Joseph
Mathews, John W.
Matjasic, Wallace L.
Mollere, John C.
Reel, C. E.
Saunders, L. W.
Sloat, John
Taylor, DeWitt E.
Terry, R. D.
Turner, Dale E.
Berkeley
Smith, James A.
Beverly Hills
Wilson, Clyde H.
Woodard, D. H.
Brawley
Smith, Warren H.
Burbank
Gayman, W. H.
Selby, Ernest R.
Chico
Scamman, Joy
Chula Vista
Geyer, Robert L.
Eureka
Horton, H. M.
Fresno
Dunlap, Robert C., Jr.
Gaby, Phil P.
Glendale
Dodd, Lavon C.
Waterfall, Louis N.
Los Angeles
Adams, John A.
Batchelder, Dean E.
Boccalery, Michael A.
Clark, R. W.
Cole, J. Gordon
Dehlinger, Peter
Desmond, Jack M.
Dresbach, C. H.
English, Walter A.
Erickson, E. L.
Gabriel, V. G.
Jakosky, J. Jay
Kempsky, Phillip J.
Leathers, C. H.
Lester, O. C., Jr.
McCloskey, Downs
McGrady, Dupree
Price, Wiley R., Jr.
Salvatori, Henry
Shade, N. R.
Statham, Louis
Tracy, W. H.
Vallat, E. H.
Walling, Dean
Modesto
Ferber, Herbert J.
Heggblom, J. C.
Pezdek, Victor J.
North Hollywood
Van Beveren, O. F.
Oildale
Drennan, William A.
Pasadena
Benioff, Hugo
Bevier, George M.
Christie, Norman J.
Conant, E. E.
Denning, Wayne H.
Dix, C. Hewitt
Fu, Ch'eng Yi
Garber, Allen J., Jr.
Gardner, Kenneth L.
Gutenberg, Beno
Hale, C. Russell

Harding, Maynard W.
Hoover, Herbert, Jr.
Howell, B. F., Jr.
Legge, J. A., Jr.
Mace, H. G.
Mansfield, Robert H.
McLemore, Ethel Ward
Miller, Nash H.
Moran, R. B., Jr.
Myers, W. H.
Palmerston, Stewart C.
Peterson, Raymond A.
Pielemeier, E. A.
Rupnik, John J.
Slichter, Louis B.
Soske, Joshua L.
Sweet, Elliott
Thornburgh, H. R.
Washburn, H. W.
Wise, Henry F.

Reseda
Adams, Robert W.

Sacramento
Cohick, Kenneth S.
Waterman, Joseph C.

San Bernardino
Eichelberger, Martin, Jr.

San Diego
Brown, Leon D., Jr.
Urick, R. J.

San Francisco
Cox, Harris
Hill, Roy A.
Hillis, Donuil
Lynton, Edward D.
Mitchell, Fielding L.
Musgrave, Albert W.
Rugg, Allen M., Jr.
Stoneham, S. C.
Ward, Dwight E.
Williston, Samuel H.

San Gabriel
Sorge, B. W.

San Marino
Johnson, Curtis H.

South Pasadena
Nomann, Arthur B.

Terminal Island
Carter, Ray K.

Whittier
Moore, Horace S.

COLORADO

Boulder
Longley, W. Warren

Denver
Aurand, Harry A.
Boos, C. Maynard
Cox, Charles B.
Duffner, Ralph T.
Hathaway, Claude M.
Heiland, C. A.
Jones, J. Byron
Manning, A. B.
McCready, H. J.
Murray, Matthew T.

Durango
Sullivan, J. M.

Fort Collins
Stommel, Harrison E.

Golden
Coolbaugh, David F.
Levings, W. S.
O'Boyle, Charles C.
Pawley, Julian K.

Kittredge
Zenor, H. M.

La Junta
Ballard, James A.

DELAWARE

Wilmington
Budd, Montgomery R.
Hardin, Neal H., Jr.

DISTRICT OF COLUMBIA

Friendship Station
Straley, H. W., III

Takoma Park
Lash, Charles C.

Washington
Beresford, Robert
Brenner, Morris
Cronin, Eugene J.
Dobrin, Milton B.
Erickson, Anton
Evinger, H. H.
Gerdes, C. H.
Gilmore, Marion H.
Gould, Martin J.
Heroy, William B.
Hoffman, Malvin G.
Jaques, Alvin T.
Kaiser, George B.
Kendall, James M.
Kimble, Henry R.
McGhee, George C.
Mott-Smith, L. M.
Muzzey, David S.
Nisle, Robert G.
Paslay, L. C.
Ritzmann, O. F.
Smith, R. Ellis
Steele, W. E., Jr.
Terry, Melvin C.
Van Orstrand, C. E.
Willis, Floyd, Jr.

FLORIDA

Coral Gables
Blanchard, William G.

Eglin Field
Nash, Cleve C., Jr.

Gainesville
Schiflett, H. L.

St. Petersburg
McCaleb, M. M.

Tallahassee
Boyd, Lewis H.
Ferguson, F. T.

Tampa
Ludwick, C. C.
Nash, John M.

GEORGIA

Fort Benning
Hannum, Robert C.

ILLINOIS

Chicago
Cram, Ira H.
Parkhurst, George L.

Mattoon
Stratton, Everitt F.

Mt. Vernon
Rutherford, H.

Robinson
Davies, Nathan C.

Roodhouse
Dunaven, W. A.

INDIANA

Goshen
Hostetler, G. W.

LaFayette
Serviss, Fred L.

West Baden Springs
Birkenhauer, Henry F., S. J.

KANSAS

Concordia
Craig, Robert L.

Herington
Hatheway, Joseph G.

Kingman
Hurd, Clinton O.
Johnson, E. W.

Neodesha
Smith, Louis J.

St. John
Fetzer, E. L.

Wichita
Jones, Leland W.
Mercier, Vincent J.

KENTUCKY

Lexington
Hoover, J. W.

LOUISIANA

Baton Rouge
Bloomer, P. A., Jr.

Roy, Chalmer J.
Crowley
Egan, Daniel G.
Ferriday
Gulmon, G. W.
Hammond
Sklar, Maurice
Houma
Hodgson, John H.
Jennings
Hunkapiller, B. B.
Jonesboro
Roberts, Francis A.
Kentwood
Curnutt, F. E.
Lake Charles
Bugbee, J. M.
New Orleans
Brown, L. I.
Dobrick, Edward G., Jr.
Gaby, E. D.
Holmer, Ralph C.
Hudson, Joe B.
Mehta, Abdul Khaliq
Meitzen, J. B.
Partridge, John F., Jr.
Smith, Neal J.
Todd, James H.
Treybig, B. H., Jr.
Wiley, W. B.
Opelousas
Gallaway, Roy Lee
Reichert, H. C.
Ruston
Jasper, Walter E.
Nichols, E. Turnley
Shreveport
Barret, William M.
Brayton, Arnold E.
Buchner, Harry M.
Burrows, B. B.
Caster, E. L.
Crain, Ashton
Donnelly, V. T.
Fischer, L. F.
Freeman, L. I.
Hollingsworth, W. Wise
Horn, J. W.
Hurry, Clare N.
Keen, C. D.
Lea, W. T.
McLaren, R. L.
Rosenkrans, R. R.
St. Clair, D. W.
Schmidt, K. H., Jr.
Smith, C. B.
Spencer, Leslie C.
Taylor, John E.
Wells, William M.
Wilson, Richard M.
Sulphur
McAlister, C. H.
Moore, James A.
Whiton, Herman F.
Thibodeaux
Forward, Fred

MARYLAND

Baltimore
Swartz, J. H.
Chevy Chase
Crowell, J. H.
Mount Rainier
Johnson, F. L.
Silver Spring
Arthur, Marion A.
Howell, Lynn G.
Lohse, John M.
Melton, Ben S.
Miller, R. D.
Paddison, Louis J.

MASSACHUSETTS

Belmont
Garrett, George A.
Brookline
Maxwell, E.
Cambridge
Beers, Roland F.
Bradford, Donald C.
Horton, Claude Wendell
Houston, Charles E.
Oliphant, Charles W.
Siegert, Arnold J. F.
Smith, J. Angelo
Thompson, R. R.
Tripp, R. Maurice
Everett
Haskell, Norman A.
Taunton
Church, Joseph H.
Weston
Linehan, Daniel, S. J.
Woods Hole
Ewing, Maurice
Peoples, J. A., Jr.

MICHIGAN

Saginaw
Oudt, F. W.
Rozsa, T.
Williamston
Ferguson, Joe L.

MINNESOTA

Minneapolis
Weisbrich, R. A.
New Ulm
Pollei, Donald W.
St. Paul
Wetzel, W. W.
Virginia
Kendall, J. M.

MISSISSIPPI

Brookhaven
Kretz, Robert L.
Canton
Howard, G. C.
Forest
Marsh, Samuel R.
Warren, Kirby J.
Laurel
Walling, F. Rex, Jr.
Weber, David M.
McComb
DiGiulio, Fred J.
Martin, W. Obier
Natchez
Ferguson, J. G.
Strange, Booth B.
Picayune
Long, James A.

MISSOURI

Camp Crowder
Batson, James B.
Joplin
Latimer, M. W.
Seyffert, Willis A.
Kansas City
Fain, Edgar A.
St. Louis
Blum, Victor J.
Macelwane, James B., S. J.
Robertson, Florence
Stearn, Noel H.

MONTANA

Billings
Cady, Francis H.

NEBRASKA

Lincoln
Bates, Charles C.
Souther, J. B.

NEW JERSEY

Asbury Park
Loring, Ralph C.
Bayonne
Flude, J. W.
Dover
Hawkes, H. E., Jr.
Gibbstown
Burrows, L. A.
Montclair
Siegel, Frank
Mountain Lakes
Stanton-Ross, John Taylor

NEW MEXICO

Artesia
Whelan, Mark
Hobbs
Moore, J. Hiram
Thompson, Grady
Livingston
Jones, R. W.
Lovington
Allon, Michael

NEW YORK

Amawalk
Kelly, Sherwin F.
Garden City
Doolittle, Russell C.
Hempstead
White, Gifford E.
Witt, M. K., Jr.
Ithica
Baird, John
Lido Beach
Stover, Edward B., Jr.
Mineola
Westrick, Edmond W.
New York
Albright, E. G.
Bowsky, Merle C.
Gibbon, H. A.
Golden, John M.
Haight, H. W.
Hardy, Willis W.
Hubbard, Bela
Jansen, M., Ir. J. J. H.
Kaufmann, G. F.
Lynch, J. Joseph, S. J.
Milstein, Mark N.
Olson, W. S.
Pakiser, Louis C., Jr.
Pekeris, C. L.
Piety, R. G.
Rieber, Frank
Schoellhorn, Henry, III
Schwennesen, A. T.
Skeels, D. C.
Weichert, R. F., Jr.
Woodward, R. H.
Zavoico, Basil B.
Rochester
Tompkins, Frederick A.
Wellsville
Young, Wilber H., Jr.
West Point
Honnell, P. M.

NORTH CAROLINA

Camp Lejeune
Ervin, Lynn D.
Davidson
Foster, Edward S., Jr.
Durham
Stick, John C., Jr.
Ft. Bragg
Imle, Harry R.
Raleigh
Miller, E. L., Jr.

NORTH DAKOTA

Bismarck
Renden, Hugo R.

OHIO

Cincinnati
Day, Charles E.
Dayton
Koenig, Palmer, E.
Meador, Bernal M.
Smitherman, Lynn A.
Middleport
Hersey, J. B.
Portsmouth
Howe, Ralph H.

OKLAHOMA

Alva
Butler, W. W.
Bartlesville
Beck, August F.
Bondurant, J. E.
Brownlow, C. L.
Courtier, William Henry
Crenshaw, C. C.
Dietert, Arthur E.
Dissler, Ernest
Ericson, Harry B.
Haig, Ardris
Hintze, A. J.
Kidd, Robert L.
McNally, P. M.
Miller, Vincent
Owen, H. J.
Wolters, Earl M.
Clinton
Fischer, Leon
Enid
Clifton, R. L.
Garner, J. P.
Guthrie
Kittredge, F. R.
Healdton
Smith, Mrs. Francis E.
Norman
Schriever, William
Oklahoma City
Feather, V. G.
Maxey, J. R.
McMullin, Elbert F.
Trombla, L. B.
Ponca City
Athy, L. F.
Crawford, John M.
Haber, A. F.
Hughes, Roland F.
Jordan, C. K.
Mount, E. L.
Northcutt, W. C.
Prescott, H. R.
Richards, L. J.
Searcy, Frank
Swan, Bird G.
Vorheis, Byron
Warren, Paul R.
Whitehead, L. E.
Shawnee
Buck, R. D.
Lukens, John P.
Smith, D. F.
Tulsa
Acheson, Volney A.
Anderson, John F.
Barthelmes, Albert J.
Baum, Robert
Becker, H. C.
Bevan, Thomas J.
Bills, Robert N.
Bishop, F. L.
Blight, Richard E.
Borman, F. W.
Born, Milton C.
Born, W. T.
Boucher, F. G.
Bowman, D. C.
Breck, Howard R.
Brown, Henry W.
Bryan, A. B.
Buffum, C. E.
Bullock, Robert L.
Burg, Kenneth E.
Burton, R. H.
Calhoun, F. F.
Campbell, H. H.
Carter, R. W.
Clark, R. C.
Coan, G. B.
Coffin, R. Clare
Connell, Joe E.
Cooley, E. H.
Cooper, Jack R.
Cornette, J. R.
Cornish, Lou G.
Dahlberg, Robert S., Jr.
Davis, D. R.
Duller, Charles E.
Eisler, Joseph D.
Emanuel, Vincent
Emrick, D. G.
Erdahl, William M.
Evans, Julian F.
Faust, L. Y.
Fearon, R. E.
Ferguson, John L.
Ferris, Craig
Finley, R. K.

Finn, Robert S.
Fitch, A. A.
Friendly, Jack L.
Frost, Noel
Gemmer, R. W.
Gilliam, J. T.
Gilliland, J. R.
Gilmour, Andrew
Giltinan, G. M.
Goebel, Lawrence A.
Green, W. G.
Grimm, G. A.
Handley, E. J.
Harlton, Bruce H.
Hartline, Ralph E.
Hawkins, J. E.
Hays, Clyde L.
Heinrichs, W. E., Jr.
Hoffman, John C.
Hollis, Jack L.
House, A. Maxwell
Innes, Arland I.
Irby, W. L.
Jackson, J. G.
Jeffers, Paul H.
Johnson, J. R.
Jones, Huston T., Jr.
Jones, V. L.
Kendall, G. D.
Kendall, W. B.
Kezeler, J. L.
Koeppel, B. W.
Kundert, Karl H.
Lambkin, Woodrow W.
Lang, Harold M.
Larson, Carl L., Jr.
Lawrence, K. M.
Laws, J. O.
Leady, F. B.
Leverich, Priestley
Low, R. M.
Maher, John C.
Manhart, T. A.
Marston, John
Martens, Willis P.
Martin, Dick
Mayes, Tom D.
McClure, C. E.
McCollum, Elton V.
McNatt, E. M.
Mehringer, A. P.
Moore, Homer C.
Mossman, R. W.
Naremore, D. W.
Neufeld, J.
Novelly, Walter O.
Owen, J. E.
Palmer, John E.
Rankin, C. T.
Reid, A. C.
Rich, J. M.
Richardson, J. W.
Rickel, Wesley K.
Ricker, Norman
Riess, Malcolm
Roark, James J.
Robertson, K. A.
Romberg, M.
Ross, Charles M.
Rummerfield, Ben F.
Rutledge, Richard B.
Schempf, Edward G.
Scott, C. B.
Seaman, L. O.
Sharpe, Joseph A.
Sheffet, David
Sibley, W. B.
Silverman, Daniel
Southgate, Tom F.
Sparks, Neil R.
Stotler, Thomas C.
Strachan, Clyde G.
Swearingen, A. C.
Sype, William R.
Taylor, Albert
Taylor, Garvin L.
Thomas, T. J.
Thralls, H. M.
Van Croy, Stefan
Van Valkenburgh, J. C.
Vernon, Jess
Wagoner, G. E.
Waldrep, W. Day
Walton, George G.
Wantland, Dart
Watson, Robert J.
Weatherby, B. B.
West, S. Stewart
Westby, G. H.
Widess, M. B.
Wilcox, Stanley W.
Williams, P. S.
Wilson, James N.
Winn, Clayton N.
Winnek, J. R.
Woolson, John R.

Weatherford
Stones, J. Eugene

PENNSYLVANIA

Erie
Wuenschel, Paul C.

Norwood
Bazzoni, Charles B.

Pittsburgh
Affleck, James
Backman, John E.
Bailey, Lothrop H.
Barbour, P. C.
Butler, Mark D.
Cerveny, Philip F.
Cook, D. E.
Copeland, R. J.
DeGood, R. G.
DeWoody, D. A.
Diveley, Paul R.
Dombart, William F.
Eckhardt, E. A.
Elkins, Thomas A.
Gardner, Louis W.
Gealy, Wendell B.
Gemmell, Howard F.
Gunn, J. E.
Hammer, Sigmund I.
Hastings, W. K.
Herron, Robert C.
Hollobaugh, Robert C.
Hoylman, H. Wayne
Kerbow, R. B.
Kilborn, J. M.
McCracken, Guy I.
Meszaros, W. A.
Muffly, Gary
Muskat, Morris
Nettleton, L. L.
Nutt, Willard T.
O'Donnell, Thomas J.
Palmer, E. M.
Palmer, Loyal D.
Peters, Leo J.
Rasé, H. L., Jr.
Reiser, Robert G.
Robinson, W. Bernard
Ross, R. B.
Scott, D. L.
Staples, Guy W.
Texter, John W.
Tomlinson, John B.
Watson, George R.
Wert, Carl M.
Wyckoff, Ralph D.

State College
Pirson, Sylvain J.

Trafford
Carson, J. P.

TENNESSEE

Lebanon
Agee, F. H.

Memphis
Lynn, Ralph D.

Oak Ridge
Perret, William R.

TEXAS

Austin
Konz, Leo W.
Romberg, Frederick E.

Beaumont
Carson, Roe W.
Conklin, Glenn M.
Ellis, L. G.
Hollingsworth, W. E.
Millington, John W.
Nahas, J. N.
Rose, H. W.

Shafer, Russell E.
Smiley, W. G., Jr.

Bellaire
Buckner, Guy O., Jr.
Cowles, Laurence G.
Eby, A. N.
Wolf, Alexander

Big Spring
Barnes, Chester F.
Dana, R. H.

Birthright
Hargis, A. V.

Brady
Olson, O. C.

Brenham
Wiancko, Eugene

Camp Maxey
Long, John V.

Corpus Christie
Howerton, Bert P.

Corsicana
Itten, Howard

Crane
Peachee, D. A.

Crockett
Child, V. E.

Dallas
Adams, Hal R.
Agnich, Fred J.
Alcock, E. D.
Arnett, R. D.
Arnold, Kingsland
Augustat, George
Autrey, D. W.
Baird, Walter D.
Bediz, Pertev I.
Bonebrake, Walter C.
Bradley, H. W.
Brown, H. Hallock
Browning, K. A.
Cathey, John A.
Chang, Tun Yin
Clewell, Dayton H.
Cobb, Howard L.
Coit, R. B.
Collingwood, Douglas M.
Colvin, C. E.
Cortes, Henry C.
Dahm, C. G.
DeGolyer, E. L.
Dobyns, D. R.
Doering, John
Donnally, Chester J.
Doss, C. L.
Douglas, Norvel
Elms, R. G.
Everitt, James
Farrow, B. D.
Gary, J. W.
Gillin, John A.
Gray, William R.
Green, Cecil H.
Gsell, R. N.
Hamil, A. B.
Harris, B. A.
Henderson, J. B. H.
Hieatt, Herbert F.
Hightower, C. H.
Hilger, Mrs. C. L., Jr.
Hogg, W. B.
Hubner, B. J., Jr.
Hurt, Worth B.
Jackson, Robert W.
Johnson, C. Therman
Jones, M. P.
Jonsson, J. E.
Jubran, Joseph
Karcher, J. C.
Kelsey, Martin C.
Kennedy, Edward P.
Kennedy, Frank H., Jr.
Kidder, Harold J.
Lawhorn, O. T.
Livingston, E. C.
MacNaughton, Lewis W.
McBurney, Charles G.
McDermott, Eugene
McGuckin, Glenn M.
Menefee, James C.
Minton, J. P.
Mitchell, W. R.
Moon, Jake
Moore, Charles M., Jr.
Moore, F. A.
Myers, John R.
Nash, Paul E.
Newton, W. W.
Nugent, Roderick M.
Oden, A. J.
Payne, J. E.
Pellillo, M. J.
Pernell, J. H.
Perryman, J. D.
Peters, Jack W.
Pittman, C. V. A.
Pratt, R. B.
Ransom, J. H.
Ransone, W. R.
Raper, W. B.
Reagor, Edward C.
Reeves, J. R.
Renner, Darwin S.
Robinson, George W.
Rollins, J. Frank
Russek, I. W.
Russell, Dallas L.
Schley, Woodruff H.
Seifert, Wesley H.
Seiler, George E.
Shell, G. N.
Shepherd, Cuth K.
Shimek, E. J.
Shock, Lorenz I.
Smith, Randolph
Stanton, Austin N.
Steel, D. M.
Storm, Alfred E.
Stulken, E. J.
Tabor, E. M.
Thompson, Atlas H.
Thompson, R. P.
Tottenham, W. M.
Tucker, Robert L., Jr.
Van Cleave, R. F.
Walczak, Michael J.
Waller, J. A., Jr.
Walsh, T. N.
White, Rex H.
Williams, Charles C.
Williams, Floyd J.
Wilson, E. E.
Wolff, D. J.
Woods, J. P.
Woolley, William C.

Danbury
Garrett, William M.

El Paso
Cole, R. C.

Ft. Worth
Dyk, Karl
Harris, Sidon
Hunzicker, A. A.
Johnson, James F.
Ledyard, Paul H.
Lovejoy, J. B.
Morris, James L.
Normand, S. R.
Peabody, Gwendolyn
Sanders, C. W.
Sandidge, Irl, Jr.
Shugart, T. R.
Thomsen, Erik
Van Steenbergh, S. K.
Wilson, John H.

Frijole
Pratt, Wallace E.

Hamilton
Stiles, Elisabeth

Haskell
England, C. M.

Houston
Aderman, C. V.
Adler, Joseph L.
Aiken, Charles B.
Anderson, O. W.
Bader, Glenn E.
Baker, Malcolm C.
Banta, H. E.
Banta, N. H.
Barnette, L. Atmar M.
Beeth, Donald
Bennett, Roy F.
Benz, Carl V.
Berg, G. A.

Berndes, A. E., Jr.
Bertram, A. C.
Bible, John L.
Black, J. P.
Blau, L. W.
Blevins, David C., III
Bolinger, John W.
Bradley, R. M.
Briard, Vernon E.
Brooks, James A., Jr.
Broussard, C. H.
Broussard, D. F.
Brown, Andrew
Brown, Donald R.
Brown, Hart
Burnett, Arthur C.
Campbell, David B., Jr.
Campbell, F. F.
Carlton, Dave P.
Carr, G. W.
Clark, W. C.
Clayton, Neal
Conley, H. R.
Crary, Donald
Culbertson, J. A.
Davis, Donald M.
Deacon, L. E.
Deming, J. H.
Deussen, Alexander
Doll, H. G.
Dunlap, A. D.
Duty, Robert S., Jr.
Eberts, A. G.
Eby, J. Brian
Epperson, R. S.
Evjen, H. M.
Falkenhagen, H. M.
Ferguson, J. B.
Finnigan, Thomas L.
Fohs, F. Julius
Freel, J. F.
Frosch, Alex
Futral, John E.
Gardner, Derry H.
George, Fred W.
Gibson, M. O.
Giezendanner, S. S.
Gilmore, John A.
Goldstone, Frank
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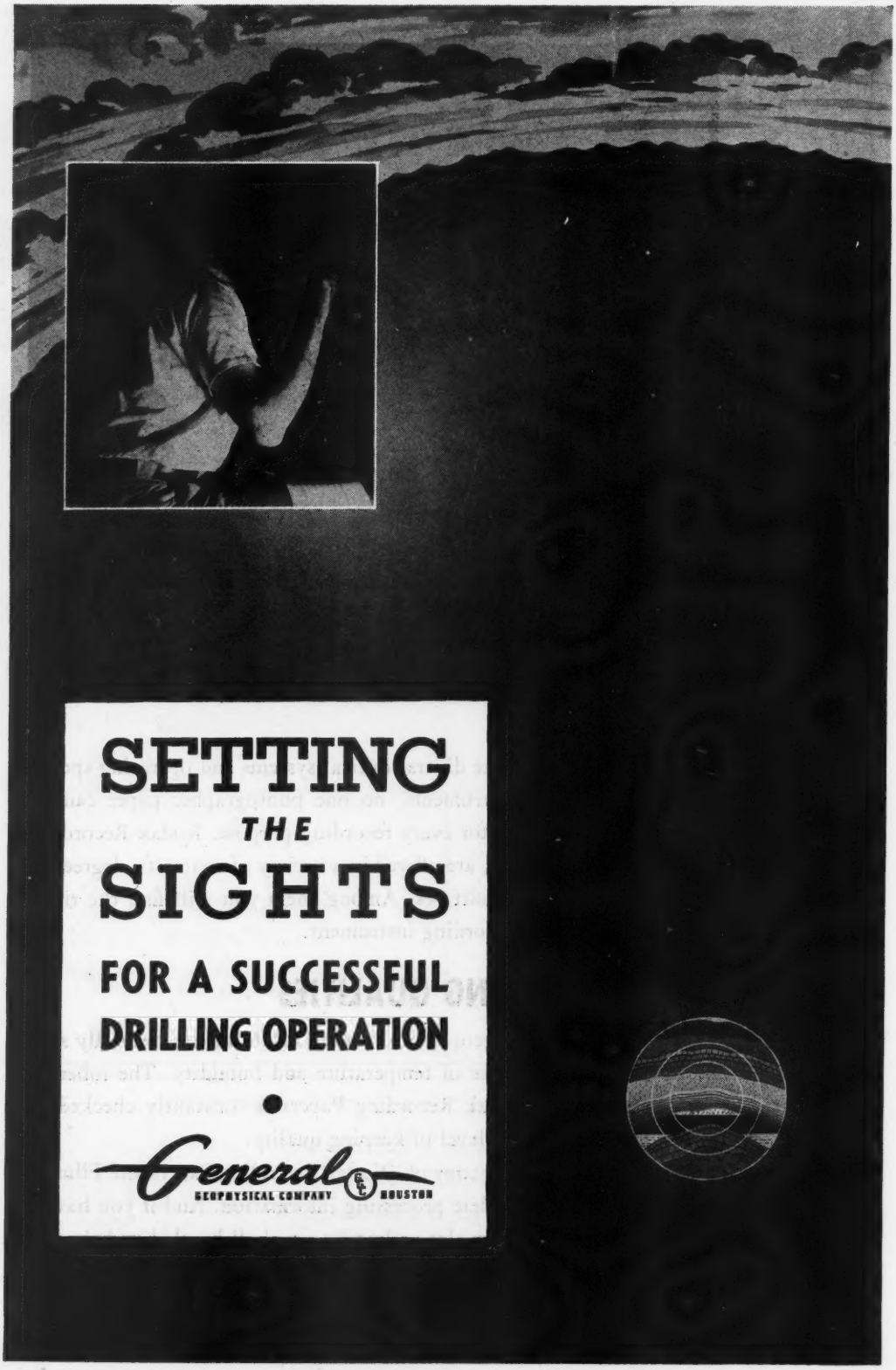
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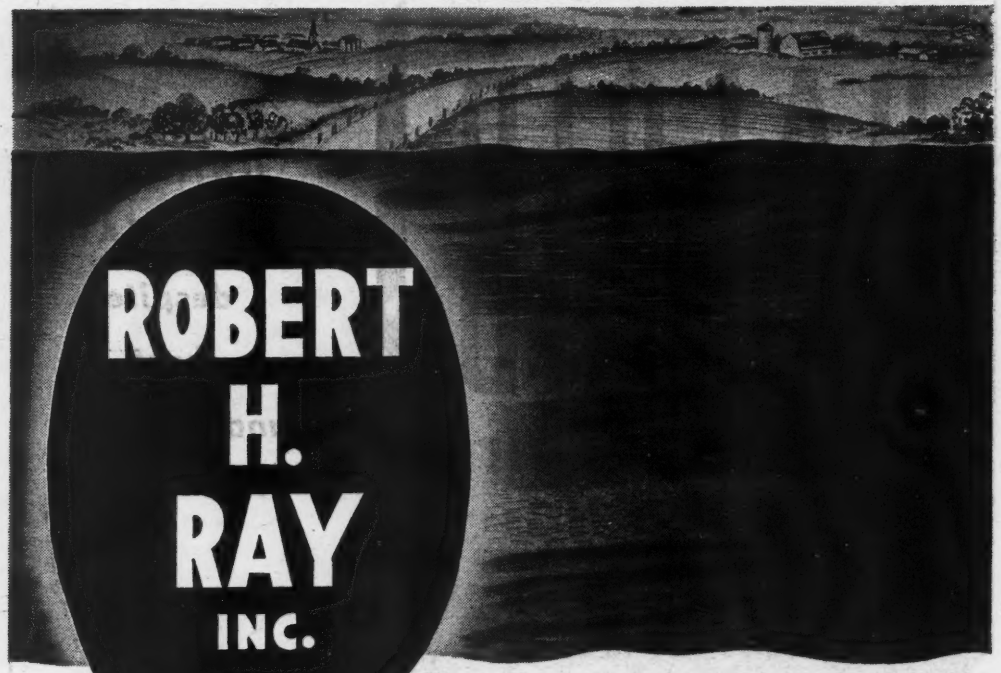

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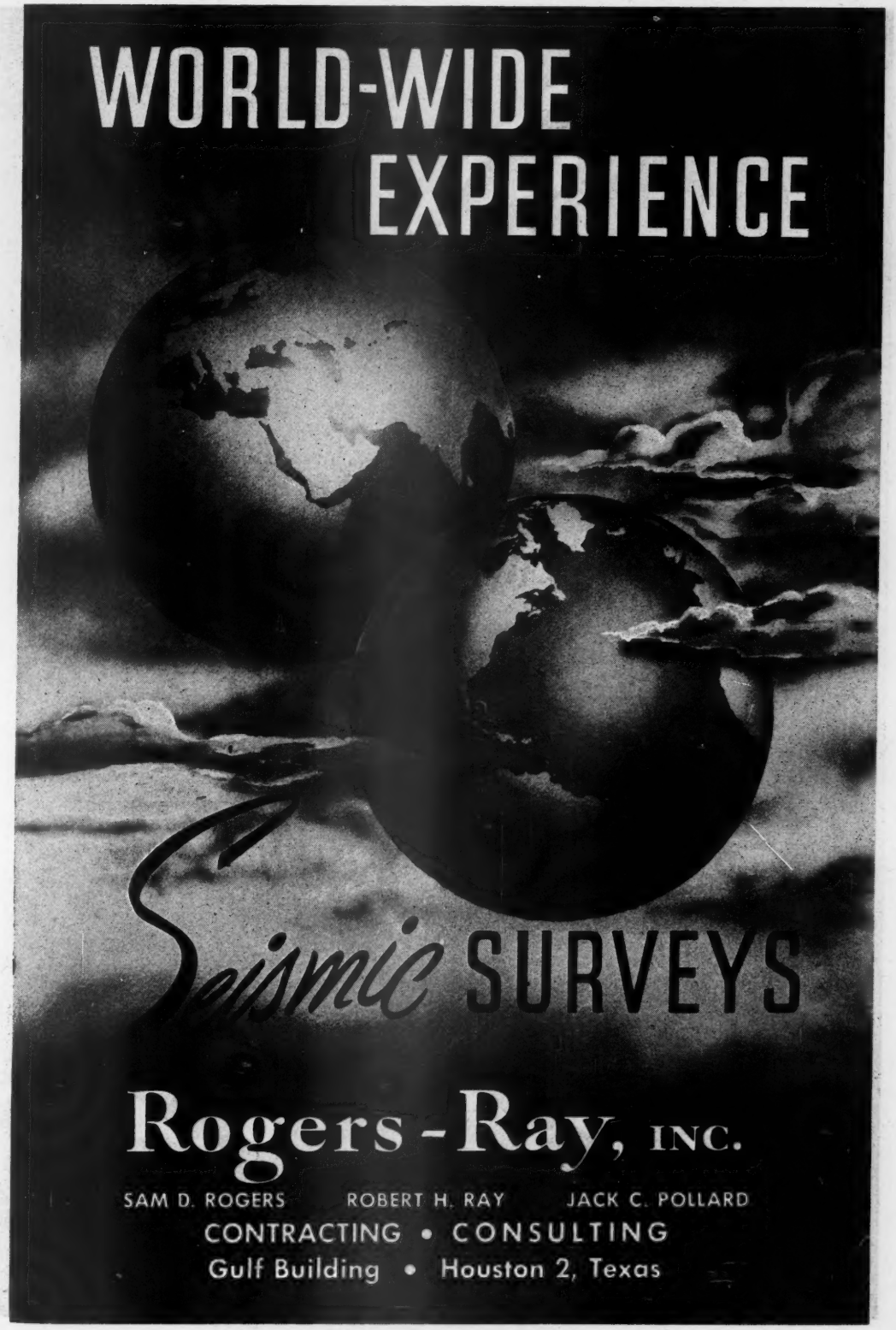
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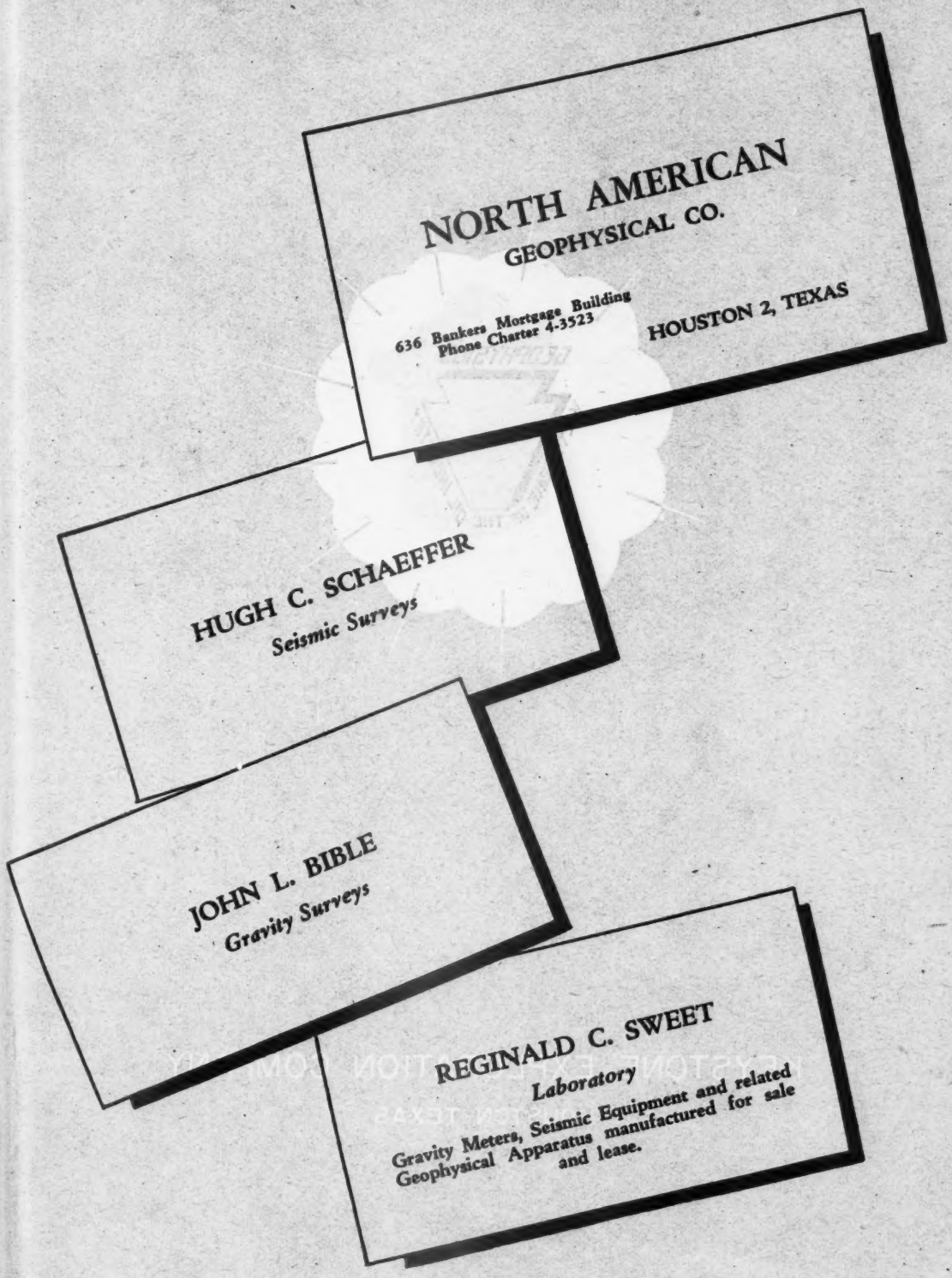
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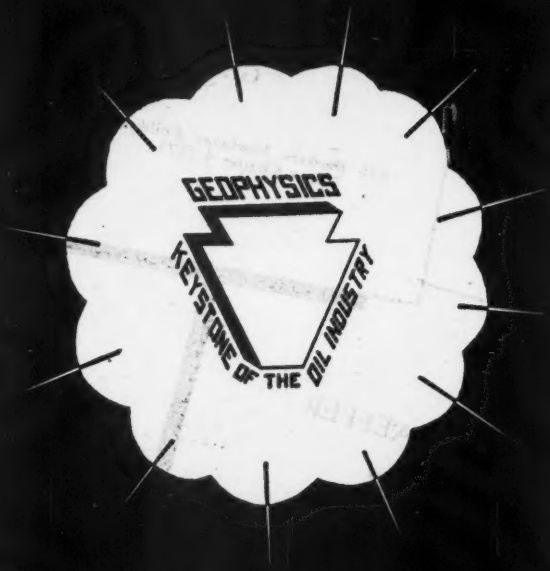

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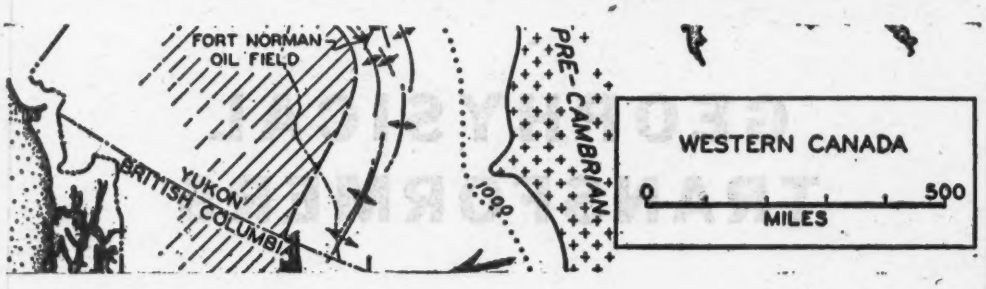

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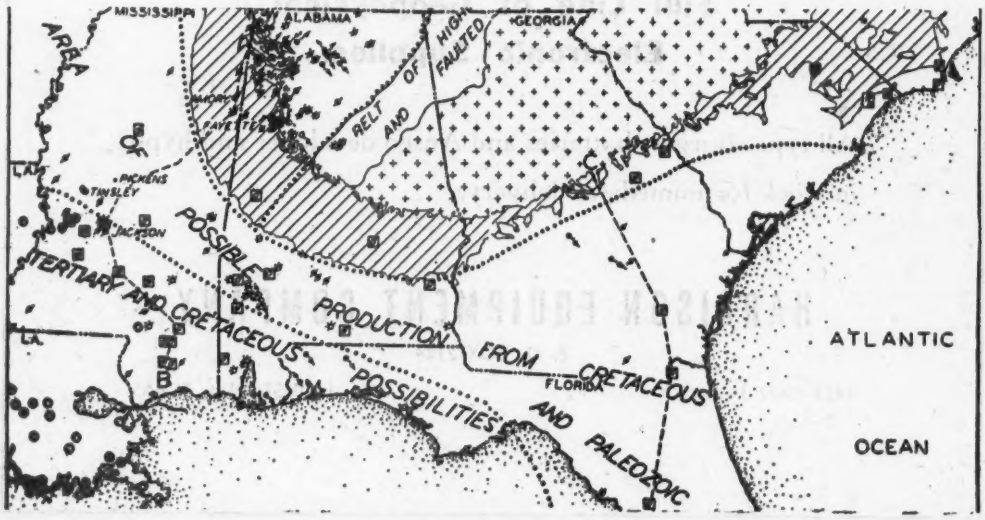

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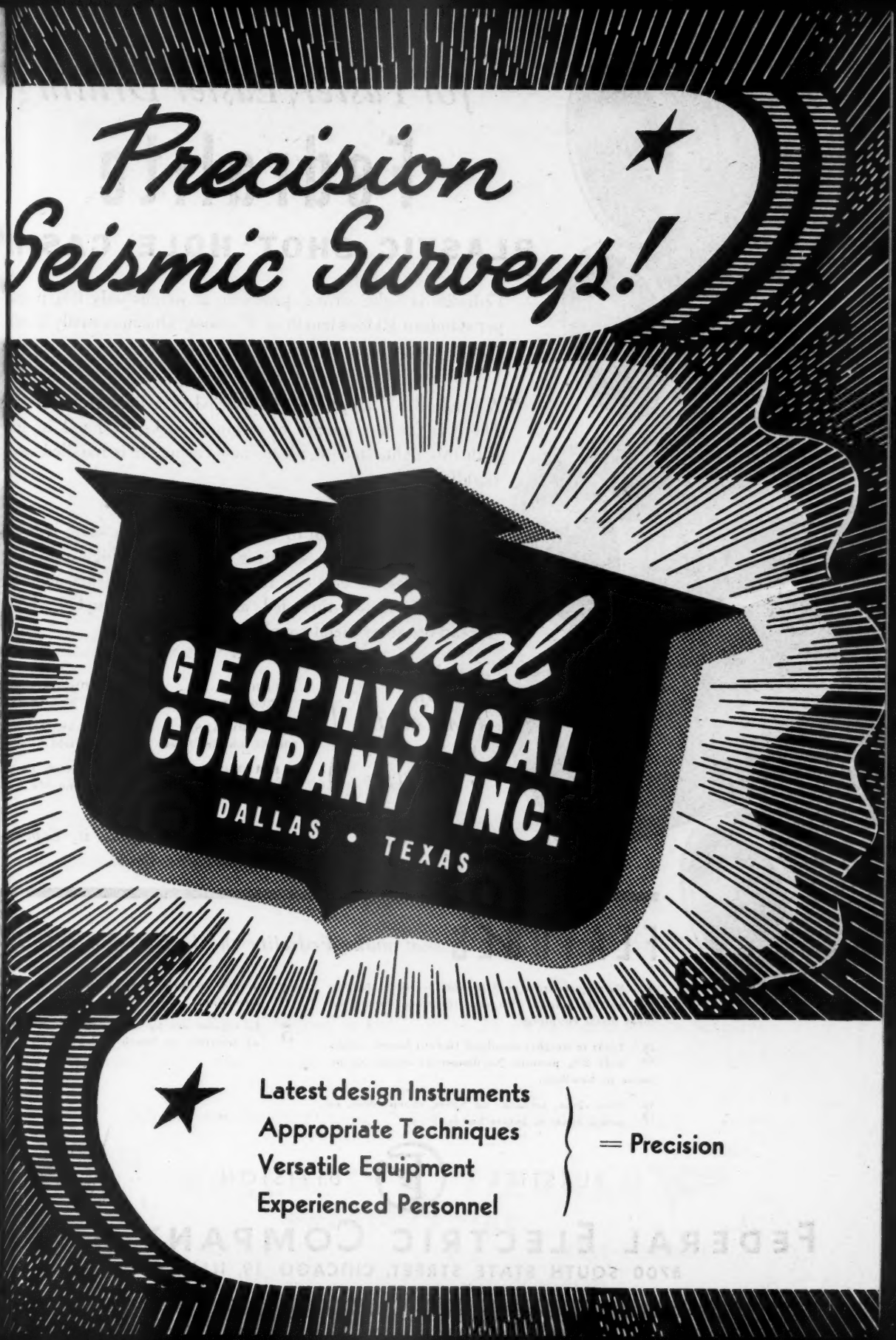
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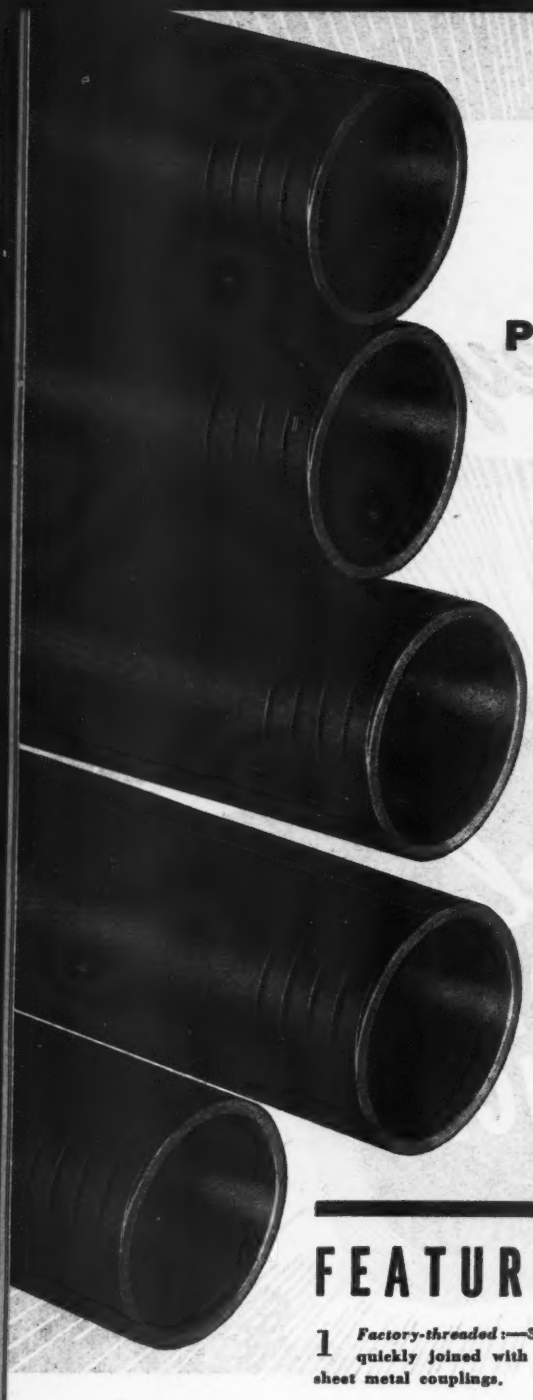

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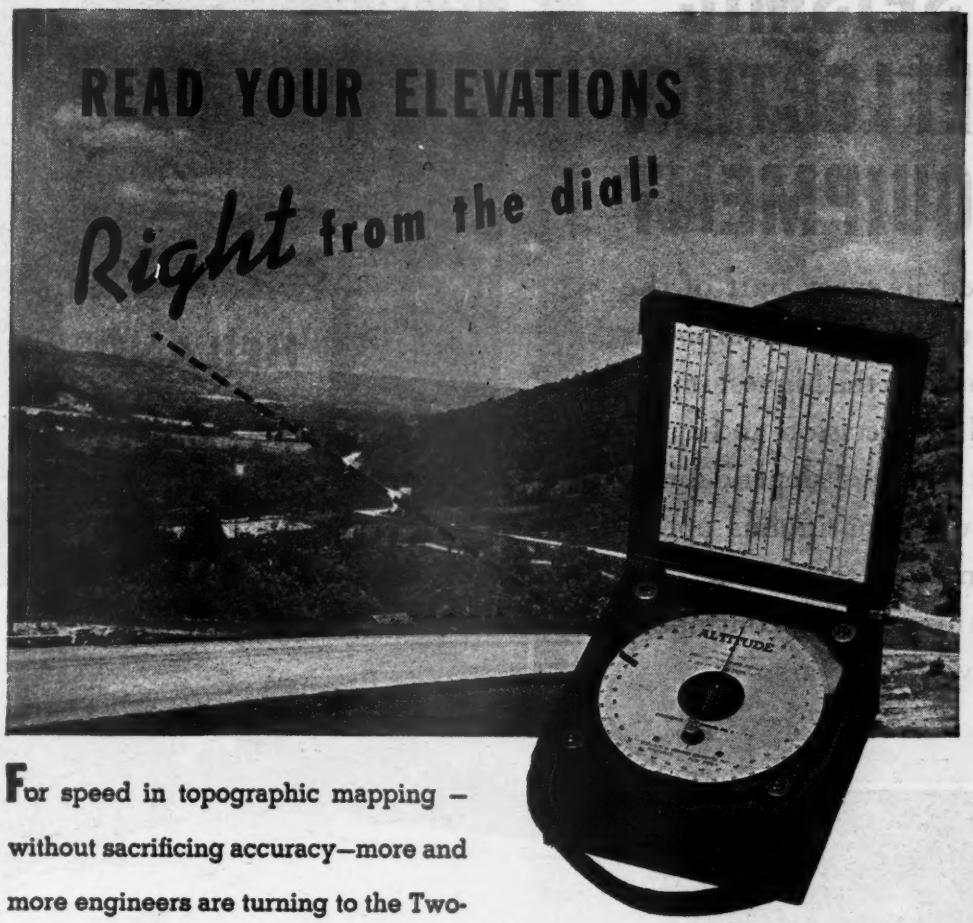

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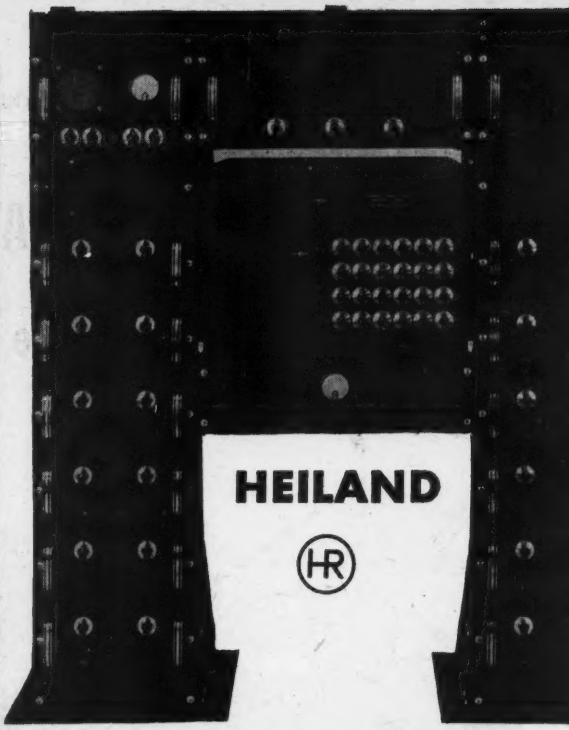

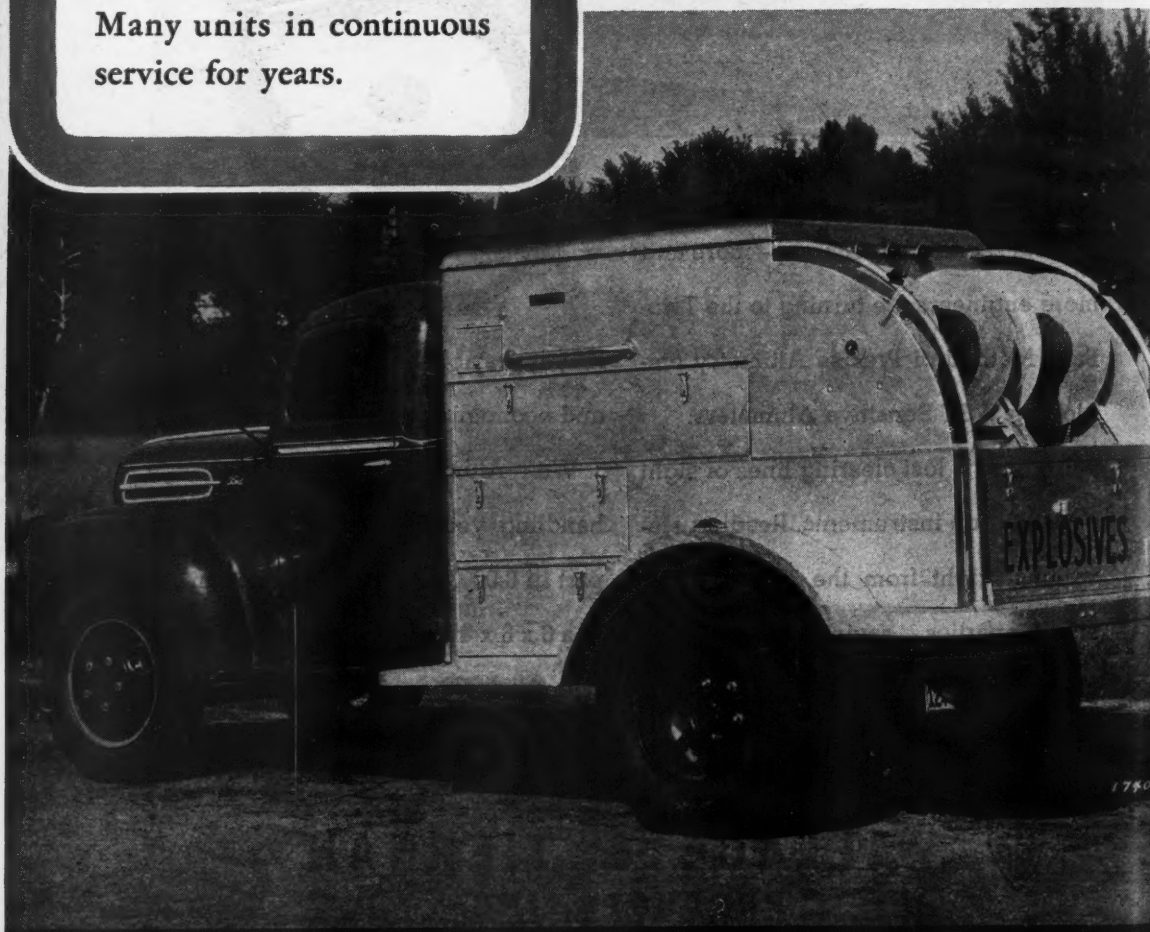

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